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Report MCR-72-91

SYSTEMS-LEVEL STUDY OF A NONSURVIVABLE JUPITER TURBOPAUSE PROBE

Volume III - Appendixes

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16. Abstract

This nine-month study of a probe to explore the Jovian atmosphere and environment included five major tasks: definition of science requirements, mission evaluation, definition of the probe system, definition of spacecraft support requirements, and nonequilibrium flow-field analysis for communications blackout evaluation.

This report emphasizes the overall mission and system design and describes the integration of the various technology efforts into complete mission designs. Included are the study constraints, science and mission objectives, mission selection rationale, and design summaries describing required engineering implementation. Critical technical problems and major trade study results are discussed.

Results showed that a nonsurvivable turbopause probe mission to Jupiter, with adequate data return to meet the science objectives, is feasible and practical within the 1975 state of the art. Many probe mission options are practical using the Pioneer or MOPS spacecraft with the 5-segment solids Titan IIID/Centaur/Burner II launch vehicle.

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FOREWORD

This final report has been prepared in accordance with requirements of Contract NAS5-11445 to present data and conclusions from a nine-month study for Goddard Space Flight Center by the Martin Marietta Corporation, Denver Division. The work was done under the management of the NASA Project Manager, Mr. George M. Levin, Advanced Plans Staff, NASA-Goddard Space Flight Center. The report is divided into the following volumes:

I - SUMMARY

II - SUPPORTING TECHNICAL STUDIES

III - APPENDIXES

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APPENDIX A

HEAT SINK THERMAL STRESS ANALYSIS

B. J. Buell & H. Hotchkiss

November 10, 1971

In a hemispherical probe shell entering Jupiter's atmosphere at high velocities, the length of survival time is critical for adequate data recovery. A structural shell of beryllium is being considered for use and has been analyzed for thermal stresses at two altitudes during entry: 70 and 80 kilometers below turbopause.

The best available method of analysis is the Wilson Axisymmetric Analysis (Martin Marietta Computer Program File Number SA005). The program permits use of multiple bilinear stress-strain curves for various temperatures of the structural material and calculates stresses and deflections resulting from a temperature variation through the thickness, and a variation around a shell of revolution by means of an iterative procedure converging on stress-strain pairs falling on or near the appropriate interpolated stress-strain curve.

The results of the -70 and -80 kilometer analyses are attached. The analytical model used (Figures A-1 and A-2) consists of elements and nodal points with corresponding temperatures. The beryllium material stress-strain curves and the respective bilinear stress-strain curves used are shown in Figure A-3. The tangential stresses versus location calculated by the program are shown in Figures A-4 and A-5 for the -70 and -80 kilometer altitudes, respectively. The resulting calculated deflections for the two altitudes are presented in Table A-I.

The maximum tensile stress in the inner row of elements occurs around 47° from the apex for the -80 km model and around 33° for the -70 km model. The calculated stress is considerably in excess of the stress from the bilinear curve at the corresponding temperature, because the program calculates effective stress from an effective modulus of elasticity. Since the calculated maximum tensile strain (0.0014 in./in.) is of reasonable magnitude and the uniaxial stress-strain curves at elevated temperatures show the beryllium unable to sustain the calculated high compressive stress, the resulting high calculated tensile stresses are not expected to cause failure unless an unexpectedly severe reduction in ductility and strength should accompany the biaxial state of tensile stress. Multiaxial tensile stress-strain data should be accumulated or actual prototype testing of the beryllium sphere should be planned if beryllium is considered for use.

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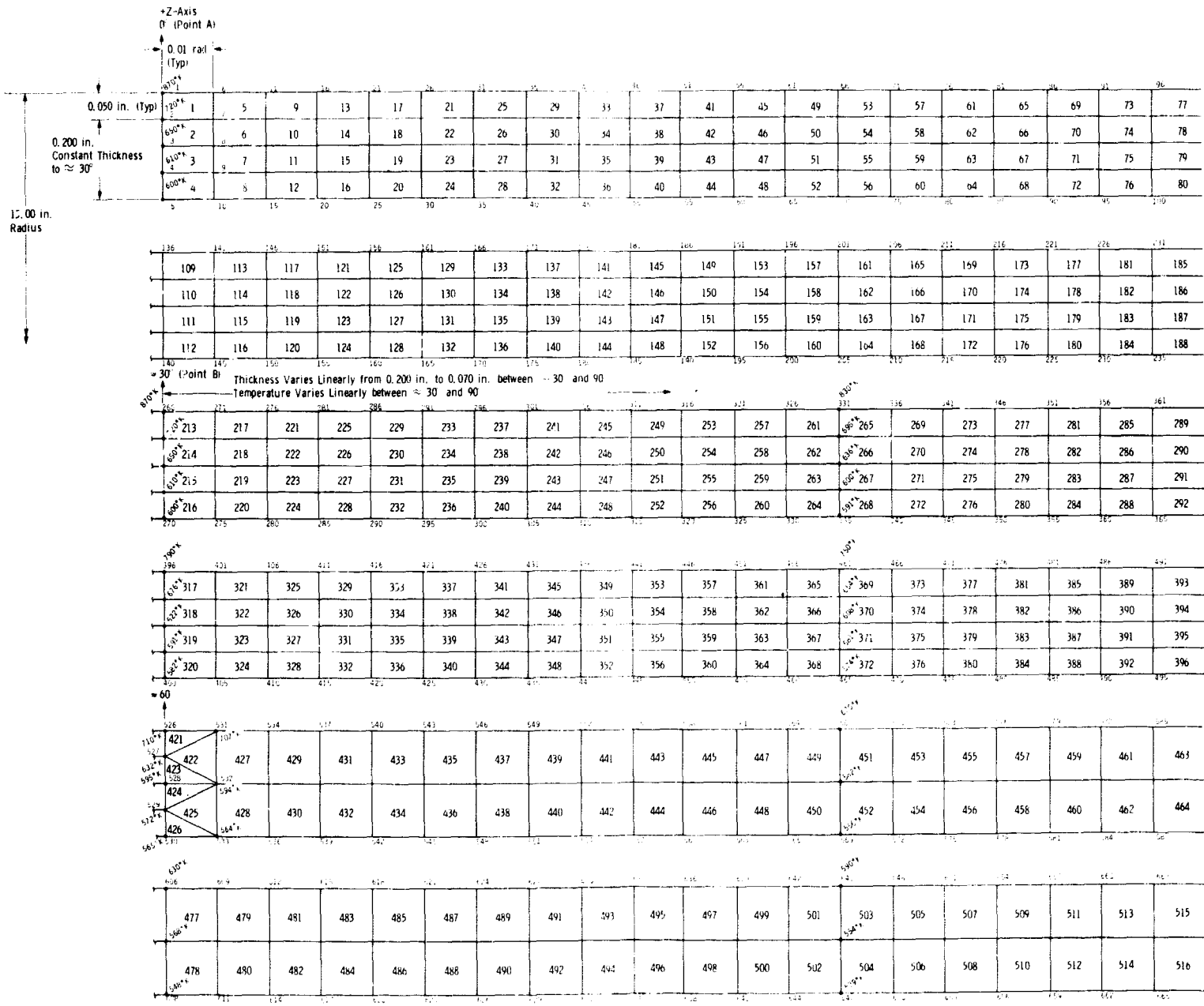
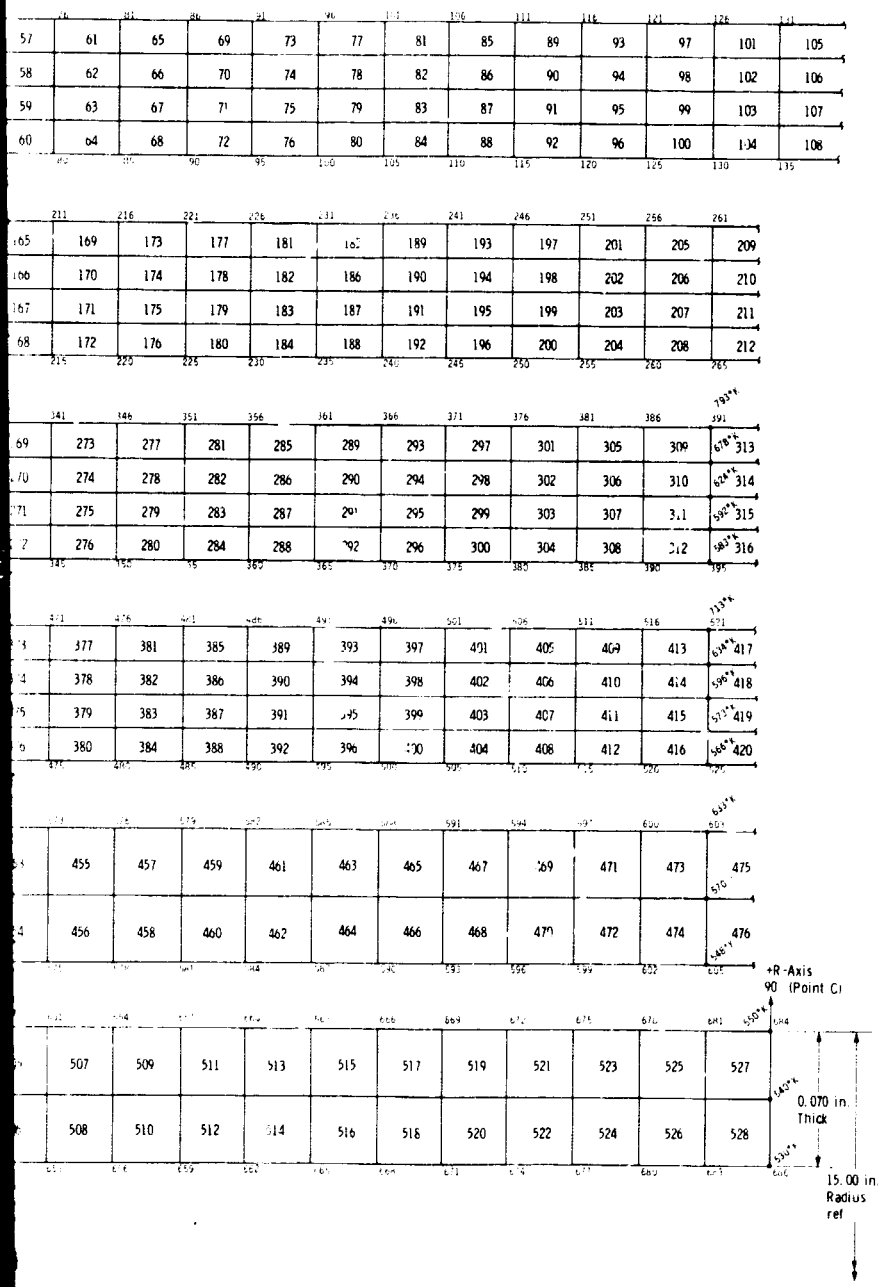


Figure A-1 Elements and Nodal Points Temperature Distribution

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mperature Distribution for Altitude 70 km Below Turbopause

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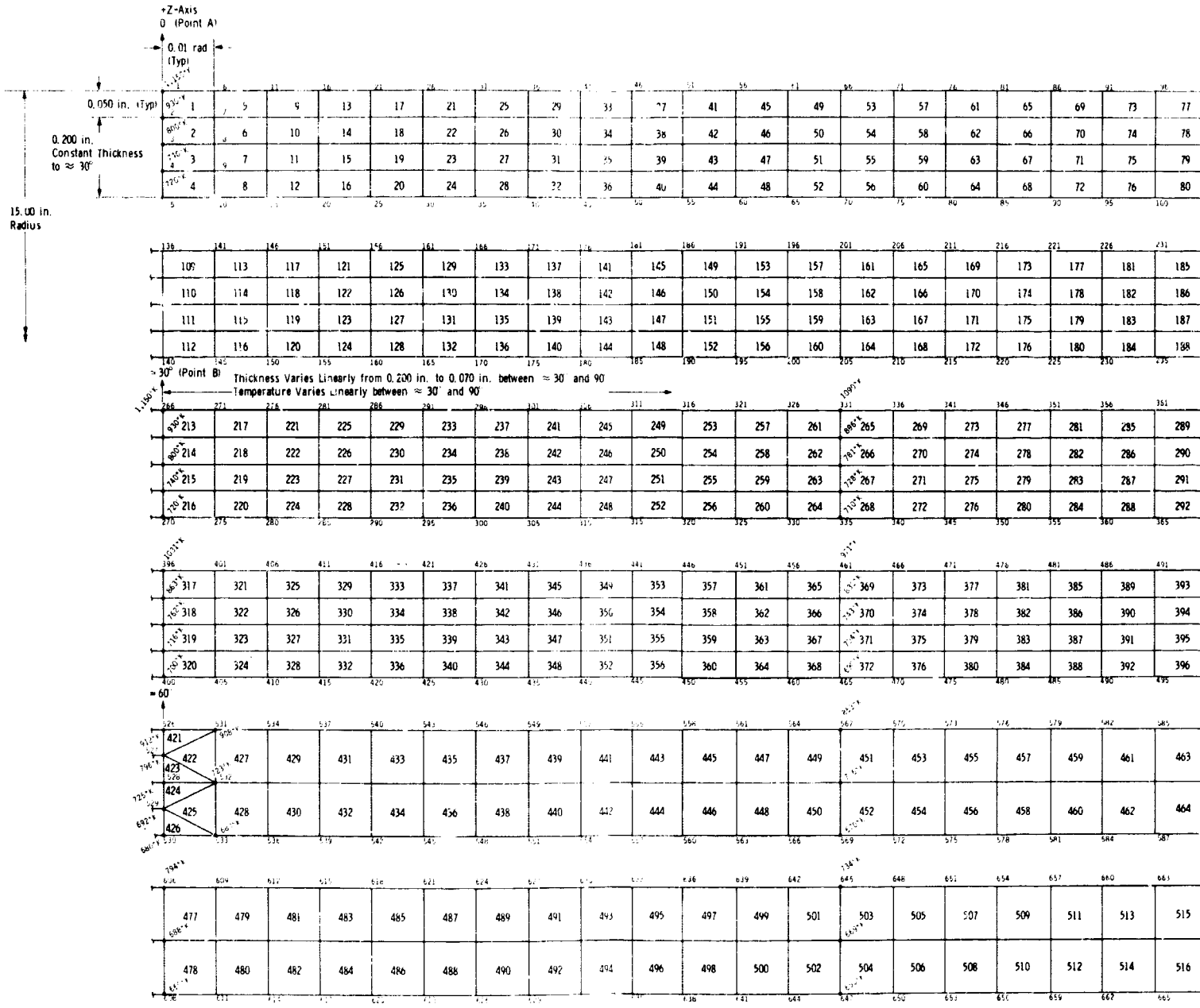
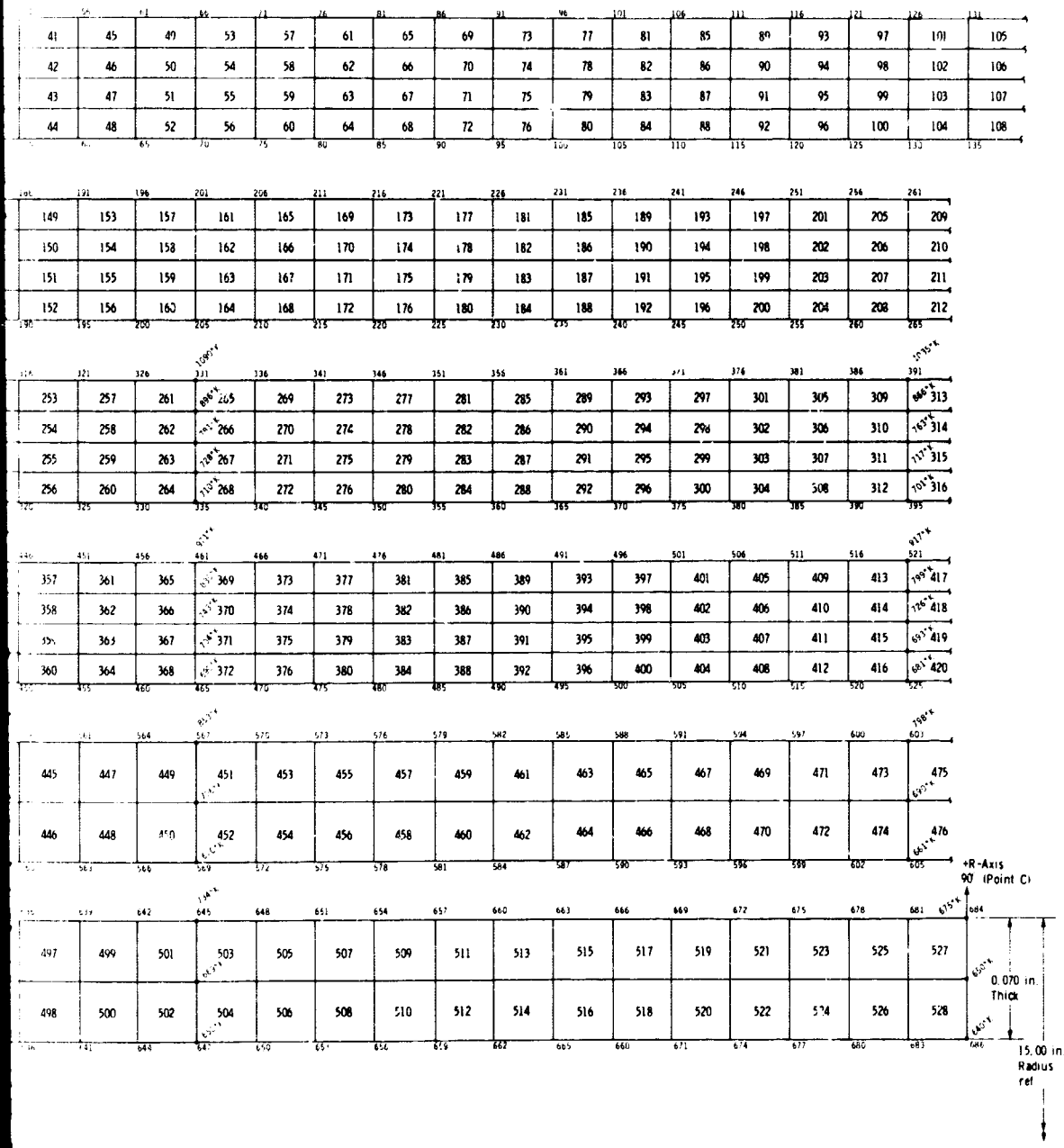


Figure A-2 Elements and Nodal Points Temperature Distribution f

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and Nodal Points Temperature Distribution for Altitude 80 km Below Turbopause

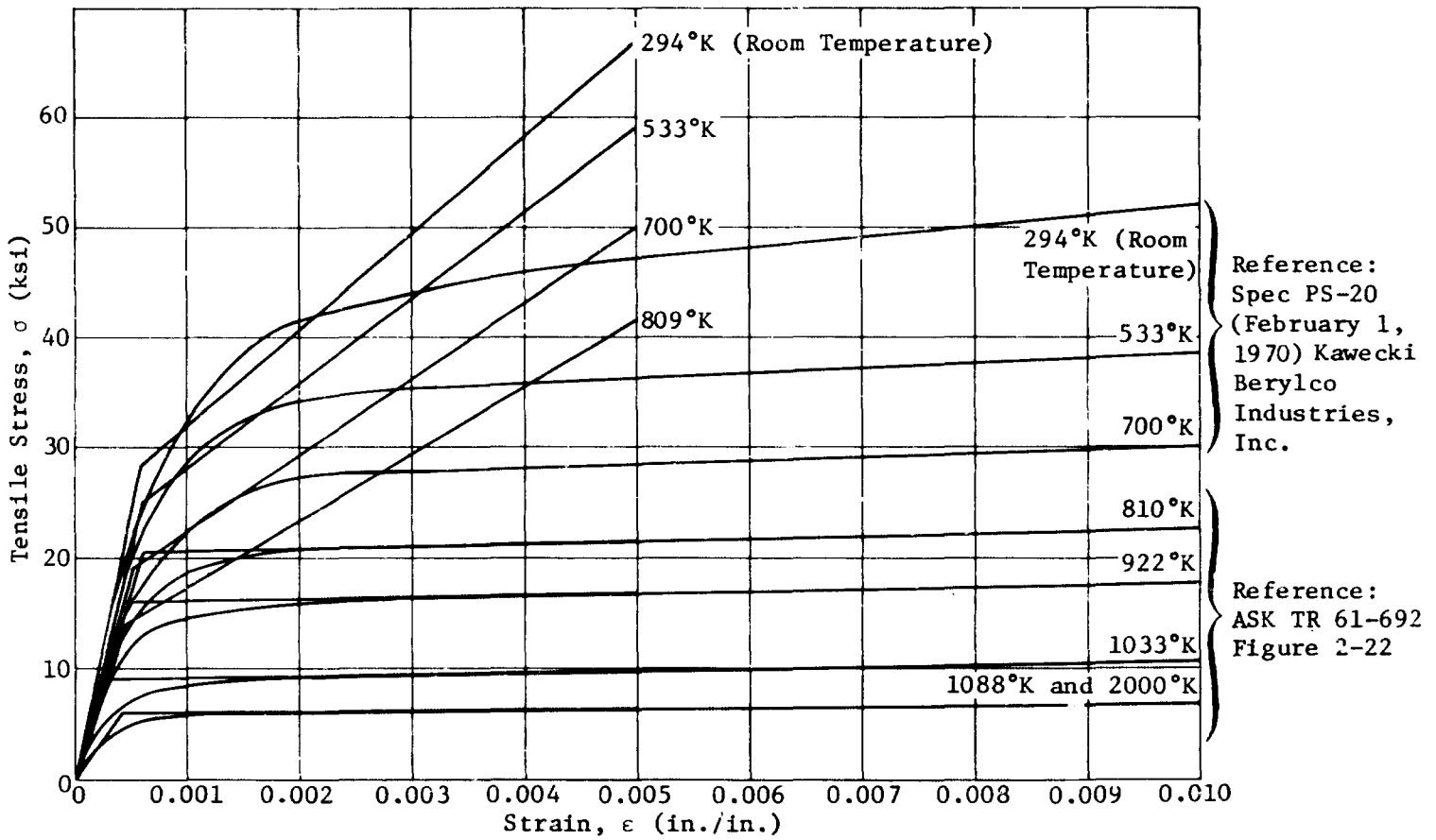


Figure A-3 Stress-Strain Curves for Hot-Pressed Beryllium

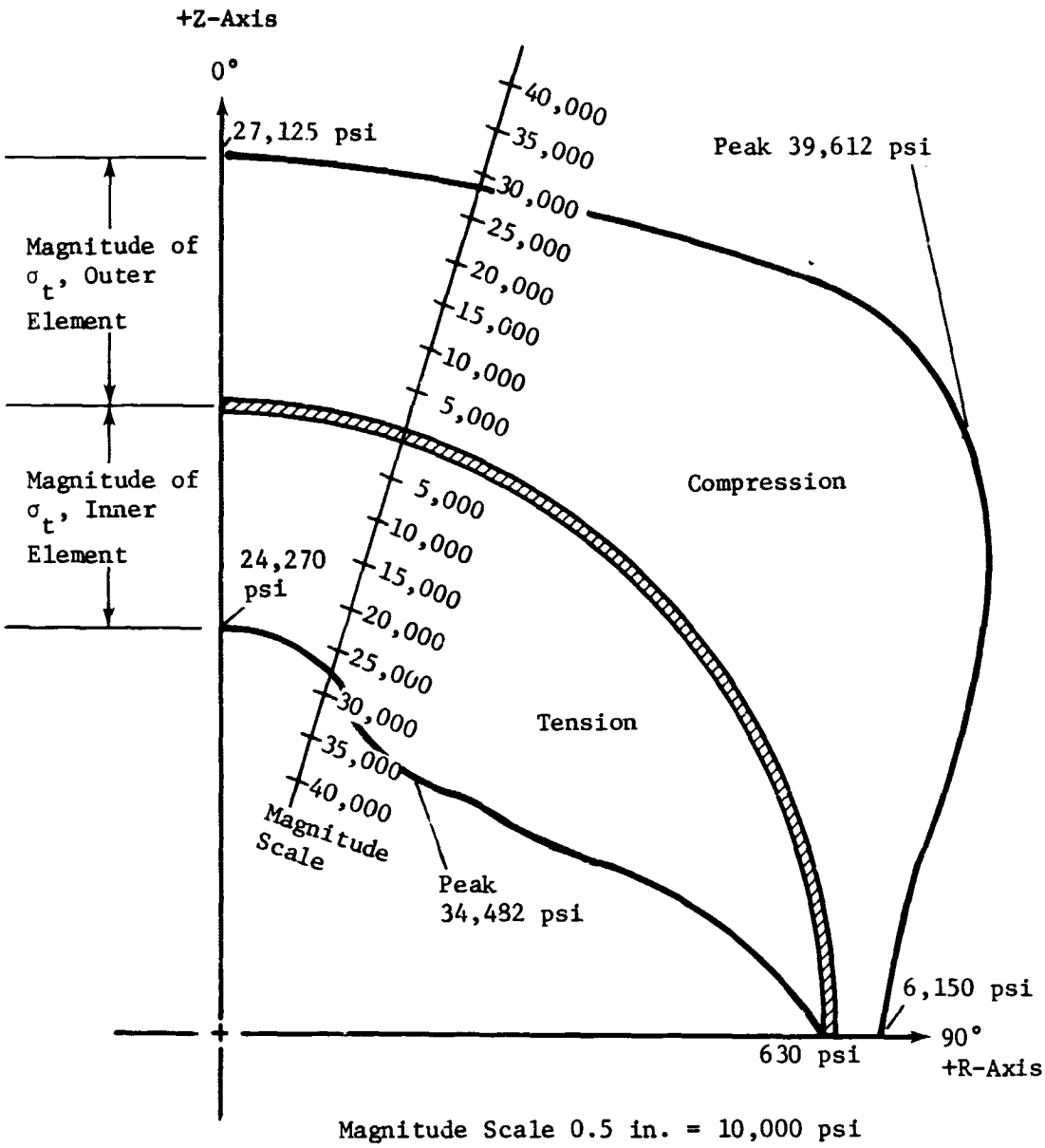


Figure A-4 Tangential Stress, σ_t for Outer and Inner Elements; Altitude, 70 km below Turbopause

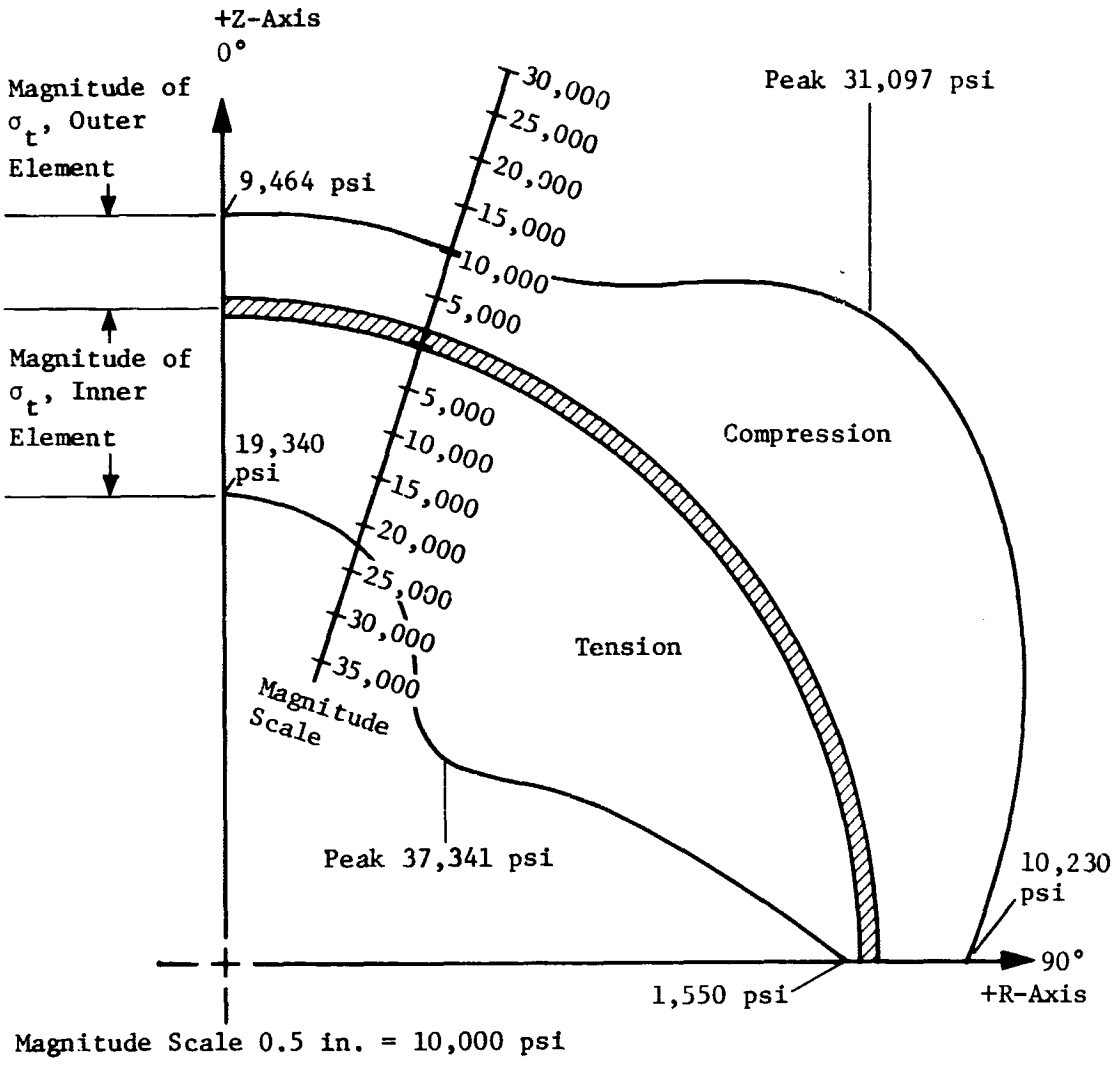
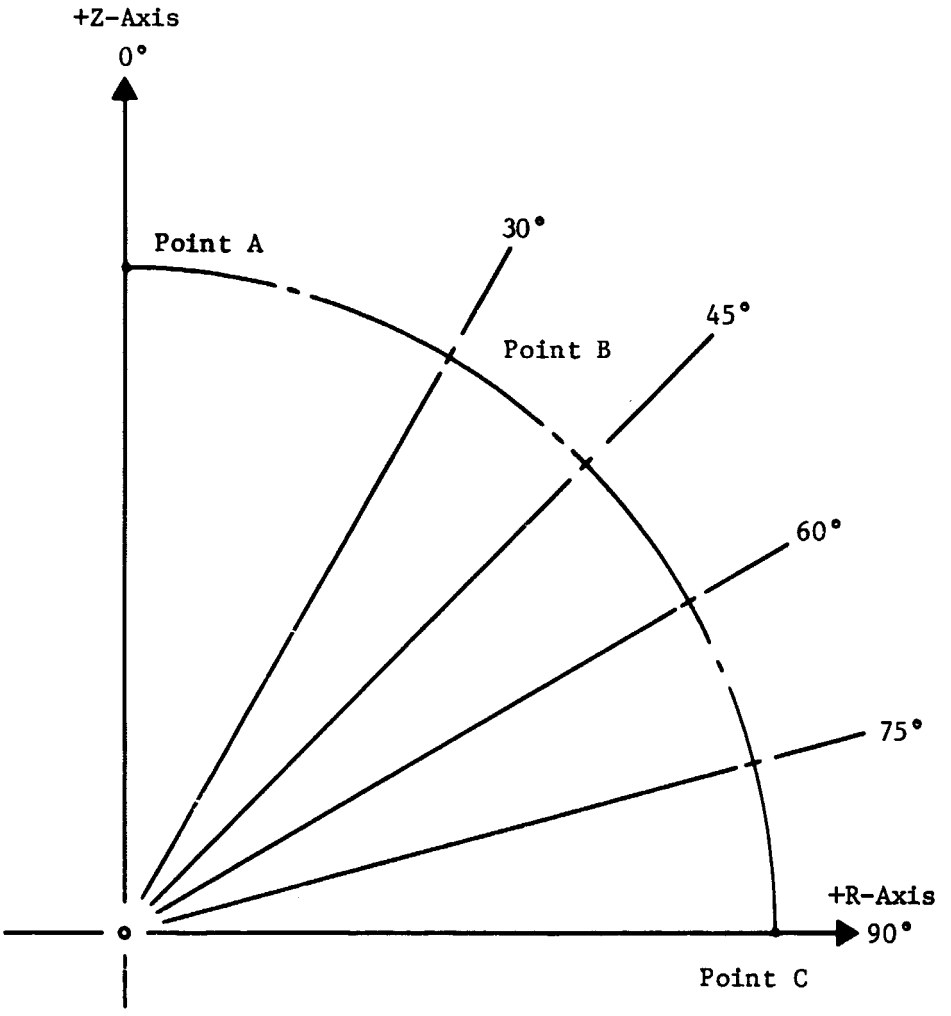


Figure A-5 Tangential Stress, σ_t for Outer and Inner Elements; Altitude, 80 km below Turbopause

Table A-I Deflection



Point Location	Centerline Deflections, (in.)			
	Altitude, 70 km Below		Altitude, 80 km Below	
	R-Axis	Z-Axis	R-Axis	Z-Axis
A at 0°	0.000	0.081	0.000	0.113
B at 30°	0.041	0.070	0.058	0.100
B at 45°	0.053	0.053	0.078	0.078
B at 60°	0.060	0.034	0.088	0.050
B at 75°	0.059	0.016	0.090	0.024
C at 90°	0.051	0.000	0.078	0.000

APPENDIX B

SOLID PROPELLANT ROCKET MOTOR EXHAUST PLUME STUDY

A. Reichert

February 25, 1972

The effect of solid particulate exhaust matter from the solid rocket deflection motor impacting the spacecraft could pose a problem for the spacecraft surface or science instruments. It was found that most existing exhaust plume computer programs were applicable for gaseous exhaust products only, and limited funding precluded the adaptation of a Martin Marietta computer program for solid rocket motor exhaust plume analysis.

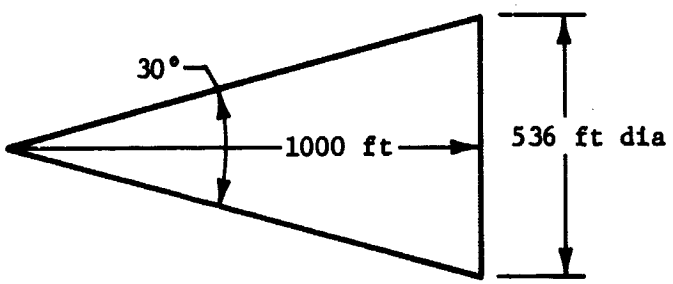
The solid particulate matter in a solid rocket motor exhaust plume remains within the projected cone of the motor nozzle, and when fired in a vacuum, maintains its nozzle exit velocity. To prevent this particulate matter from impinging upon the spacecraft, a dual nozzle motor design was proposed; this design directs the particulate matter away from the probe axis which is aligned with the spacecraft.

An alternative approach investigated was the ignition of a single nozzle (axial mounted) deflection motor. In this approach, the separation distance between the probe and spacecraft was increased before deflection motor ignition. This method reduced the number of particles impacting the spacecraft as the distance increases, but does not remove the spacecraft from the path of the particles.

Relative costs of single and dual nozzle motors and tolerance of spacecraft and instruments to small quantities of exhaust product impingement should be considered in greater detail before final design selection.

Several solid propellant rocket motor manufacturers were contacted with respect to solid propellant exhaust plume characteristics in a vacuum. The concensus stated that the solid particulate matter would lie just within the rocket exhaust cone angle. This angle is generally equivalent to a 30° cone. A typical impingement analysis for the Turbopause Probe and Pioneer Spacecraft is presented in section A; the difference in the cost quoted by three of the solid motor manufacturers contacted are presented in section B; selection of the solid motor design and reason for its selection is presented in section C.

A. TYPICAL EXHAUST PLUME ANALYSIS



1) $A_1 = \frac{\pi\ 536^2}{4} = 225{,}200\ ft^2$ (cross sectional area of plume 1000 ft aft of nozzle exit).

2) Propellant weight $\left(W_p\right)$ in the motor is 6.09 lbm of which 30% is solid particulate matter; therefore 1.827 lb will be spread over 225,200 ft^2 (or 81×10^{-7} lbm/ft^2).

3) Projected area of the spacecraft is assumed to be 100 ft^2; then the total propellant impacting the spacecraft is:

81×10^{-5} lbm

$$m_1 v_1 = m_2 v_2, \quad \frac{(81 \times 10^{-5})(9 \times 10^3)}{547} = v_2$$

$v_2 = 0.0133$ ft/sec added to the spacecraft

where

m_1 = mass of particulate

v_1 = velocity of particulate

m_2 = mass of spacecraft

v_2 = velocity impacted to spacecraft from impacting particulate.

The average diameter of $A\ell_2O_3$ molecule --

$D_{ave} = 3.16 \times (0.337)^2$ microns

$= 0.358$ microns $= 0.358 \times 10^{-6}$ meters

$= 1.175 \times 10^{-6}$ ft.

The volume of a molecule $= \frac{4\pi}{3} (0.5875 \times 10^{-6} \text{ ft})^3 = 0.85 \times 10^{-18}$ ft^3

The mass of a molecule $= 247.6 \times 0.85 \times 10^{-18} = 2.1 \times 10^{-16}$ lbm per $A\ell_2O_3$ molecule.

Based on the large proportion of $A\ell_2O_3$ forming the solid particulate matter of the rocket exhaust, assume the 81×10^{-5} lbm intercepting the spacecraft is $A\ell_2O_3$. The number of molecules of $A\ell_2O_3$ then becomes:

$$\frac{81 \times 10^{-5} \text{ lbm molecule}}{2.1 \times 10^{-16} \text{ lbm}} = 38.6 \times 10^{11} \text{ molecules}$$

that will hit the spacecraft, or

$$\frac{38.6 \times 10^{11} \text{ molecules}}{100 \text{ ft}^2} = 38.6 \times 10^{9} \text{ hits/ft}^2$$

The penetration of Mylar film by these solid motor exhaust particles can be calculated as follows:[1]

$$C_1 \rho = \frac{T}{D}$$

where

ρ = particle density (g/cc)

T = target thickness penetrated (m)

d = particle diameter (m)

C_1 = penetration coefficient (cc/g)

then $T = (0.3)\ (2.7\ g/cc)\ (0.36 \times 10^{-6}\ meters)$

$= (0.81)\ (0.36)\ (10^{-6}\ meters)$

$= 0.29 \times 10^{-6}$ meters

or $T = 0.29 \times 10^{-3}$ mm

Typical exhaust products that will be included in those impacting the spacecraft are tabulated.

Exhaust product	Product quantity moles/100 gm
SiO	0.0001
$A\ell CO_2$	0.0006
$A\ell CO_3$	0.0001
$A\ell_2O_3$	0.3334

B. COST ESTIMATE COMPARISON OF OFF-THE-SHELF SINGLE AND DUAL NOZZLE SOLID ROCKET MOTORS (BY COMPANY)

1. Hercules

No off-the-shelf-motor. Cost of one inert (tooling) and two live motors delivered, plus development, is $125,000 for either single or dual nozzle design.

2. Thiokol

Single nozzle (TE-M-541) design off-the-shelf costs $3,000 to $3,500 per motor.

Modification of TE-M-541 to dual nozzle configuration $50,000, plus test of 5 motors for $40,000 more. Delivery of motors for $3,000 to $3,500 each.

3. UTC

No off-the-shelf hardware. No difference in cost between dual and single nozzle designs. Cost not available.

Micrometeroid Penetration Test Data for Plastic Materials. TN-3770092 (Viking Engineering Report), Martin Marietta Corporation, February 12, 1971

C. SELECTION OF MOTOR

A dual nozzle solid propellant rocket motor design was selected for application to the Jupiter Turbopause Probe for deflection velocity attainment. Such a design was selected because it assures there will be no solid particulate matter exhaust products impinging on the spacecraft from the probe deflection motor. It is also doubtful that an off-the-shelf motor (either single or dual nozzle) will be available for direct application to the probe without some modification. The cost of developing a single or dual nozzle motor for this application is the same (approximately $125,000). The dual nozzles centerlines should be separated by an angle of approximately 45 degrees.

APPENDIX C

PARAMETRIC STUDY OF DEFLECTION MOTOR PROPULSION SYSTEM

A. Reichert

October 18, 1971

Parametric studies were conducted on three different propulsion systems covering a total impulse range from 500 to 25,000 lbf-sec. The three propulsion systems studied were a single thruster pressure regulated GN_2 system; a single thruster hydrazine direct catalytic (liquid feed) system using a GN_2 blowndown pressurization system; and a single solid propellant motor system. All three propulsion systems delivered the required total impulse in a single firing. Propellant acquisition for the hydrazine system is not a problem as the probe is spin-stabilized prior to initiating propulsion system thrusting.

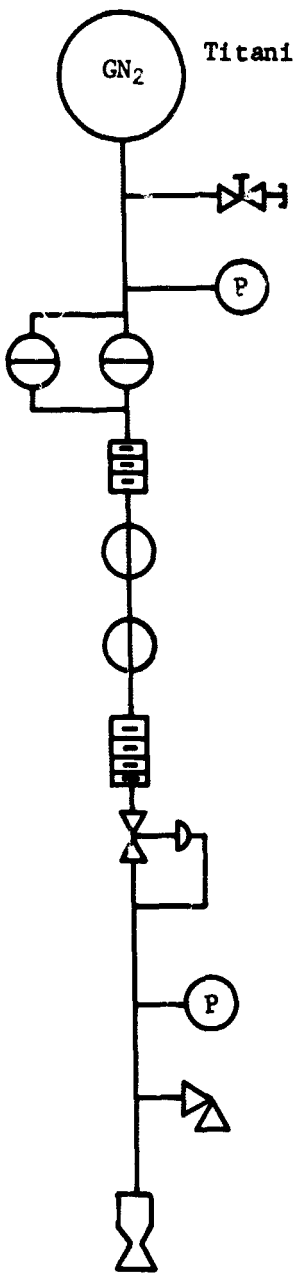
1. GN_2 Pressure Regulated Cold Gas Propulsion System

The GN_2 propulsion system studied is shown schematically in Figure C-1 and individual weights of the components comprising the feed system are indicated. The tank is initially filled to a pressure of 3500 psia, which will blow down to 200 psia during system usage resulting in a propellant residual of 5.7% by weight.

Based on past performance on many programs, titanium was selected as the tankage material. Figure B-6 of Ref 1 presents a curve of mass of propellant and tank as a function of mass of propellant for a range of propellant mass from 0.2 to 10^4 lbm. Adding the weights of the components shown on Figure B-1 to the tank plus propellant weight for a given propellant from the Ref 1 (Fig. B-6), gives the initial propulsion system mass as a function of propellant mass. For steady state operation, the system will have a delivered I_{sp} of 72 lbf-sec/lbm. The product of propellant mass and I_{sp} gives I_T (total impulse). Figure C-2 presents the resulting I_T as a function of W_{PS} (total propulsion system weight) for a range of I_T from 100 to 2500 lbf-sec.

2. Single Thruster Hydrazine Direct Catalytic (liquid Feed) System Using a GN_2 Blowdown Pressurization Feed System

This system is shown schematically on Figure C-3. Included are the system component weights (less tank, propellant and pressurant). Figure B-8 of Ref 1 presents a GN_2 blowdown feed system mass, including propellant and pressurant, as a function of propellant mass for a range of propellant mass from 0.04 to 400 lbm. Figure B-9 of Ref 1 presents a schematic of the feed system and component weights that are included in the feed system mass of Figure B-8 of Ref 1. The difference in feed system component mass between Figure B-9 of Ref 1 and Figure C-3 was added to the feed system



	lbm
Titanium Tank	
Fill Valve	0.25
Pressure Transducer	0.25
Normally Closed Valves (2)	0.50
Filter	0.35
Normally Open Squib Valves (2)	0.50
Filter	0.35
Pressure Regulator	0.40
Pressure Transducer	0.25
Relief Valve	0.3
Lines	0.2
1 lbf Thruster	0.2

Figure C-1 GN_2 Pressure Regulated Deflection Propulsion System $(3500 = P_{initial};\ 200 = P_{final})$

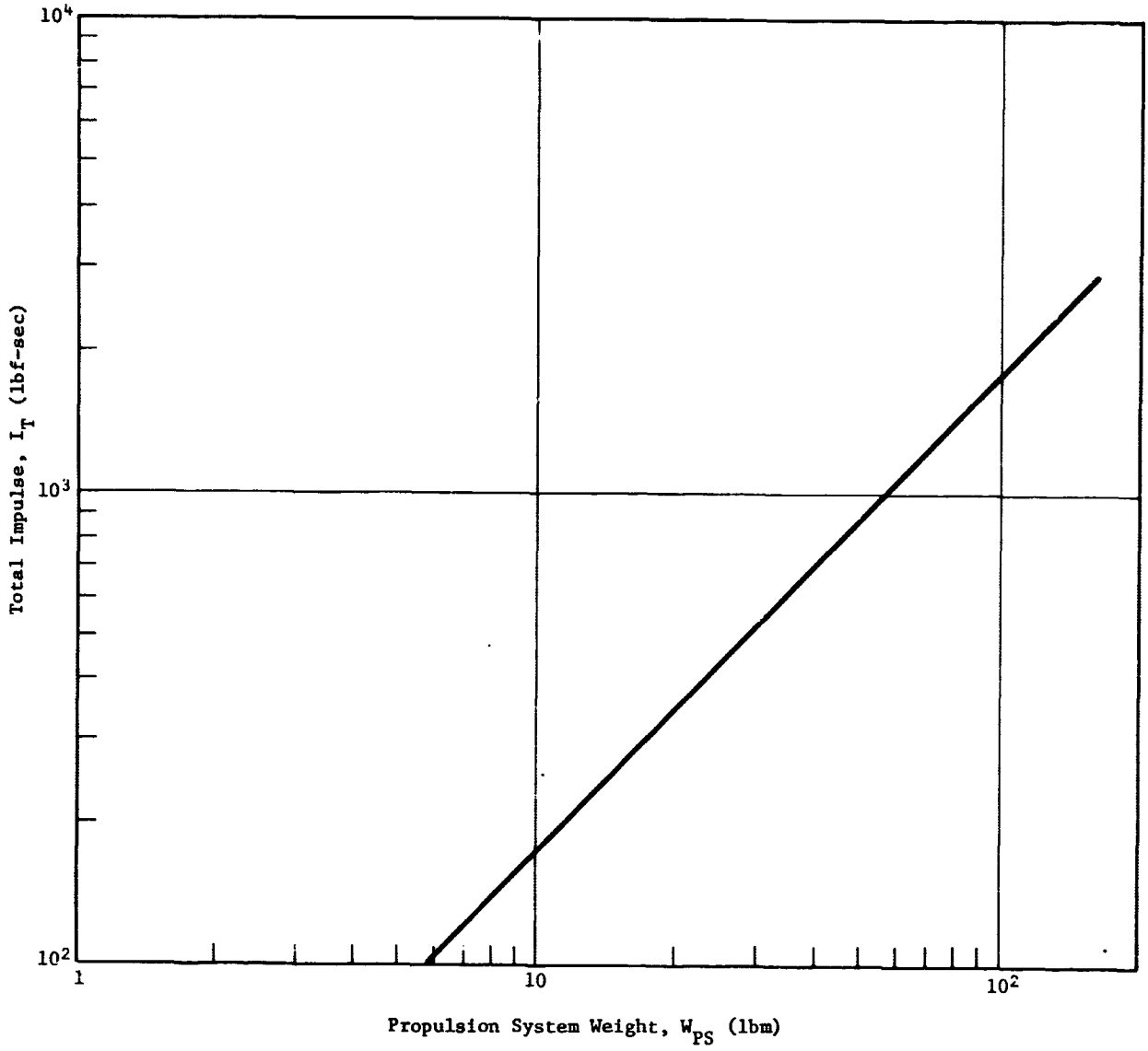
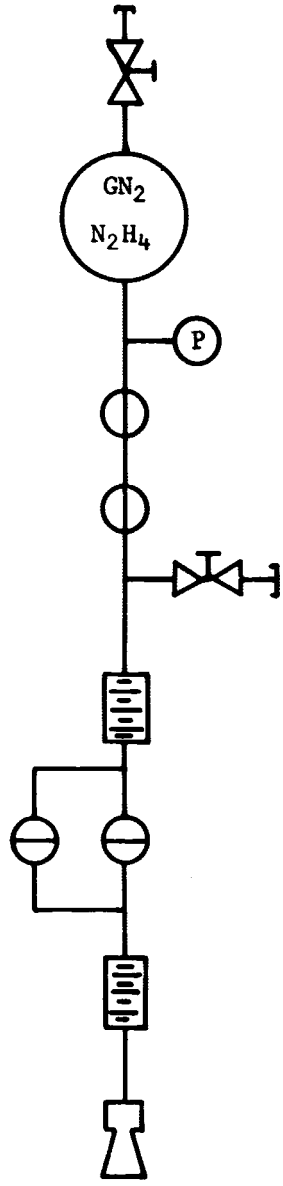


Figure C-2 I_T vs W_{PS} for State-of-the-Art GN_2 Pressure Regulated Cold Gas System



	lbm
Fill Valve	0.50
Pressure Transducer	0.41
Normally Open Squib Valve (2)	0.80
Fill Valve	0.50
Filter	0.50
Normally Closed Squid Valve	0.80
Filter	0.50
Lines, etc	2.00
Thruster	1.56

Figure C-3 Deflection Propulsion System Catalytic Hydrazine (Blowdown)

mass of Figure B-8 of Ref 1 to make the blowdown system curve apply to the Figure C-3 configuration. Figure C-4 presents the propellant fraction (λ) of the Figure C-3 configuration as a function of I_T for a range of I_T from 500 to 30,000 lbf-sec. For this system, the I_T was based on an average I_{sp} of 225 lbf-sec/lbm of propellant. A survey of this type of blowdown system indicates that a ΔI_{sp} will not exceed 2 lbf-sec/lbm. Selecting a constant I_{sp} of 225 lbf-sec/lbm will be a very close average I_{sp} approximation. Figure C-5 presents the initial weight of the propulsion system $\left(W_{PS}\right)$ as a function of I_T (total impulse).

Thrust will vary with thrust chamber inlet pressure as shown on Figure C-6. This effect must be considered when determining the time required to attain a given impulsive velocity increment, or magnitude of acceleration associated with the thrusting period. Figure C-7 presents tank top pressure as a function of percentage of propellant expended for initial tank top pressures of 300 and 400 psia. The tanks for the blowdown pressurization method are assumed to have an initial volume equal to twice that required for the propellant alone. The GN_2 pressurant is assumed to expand in a polytropic process with the polytropic exponent equal to 1.29 (obtained from Titan IIIC Transtage ACS data). A pressure drop of 20 psi is assumed from tank top pressure to thruster inlet pressure.

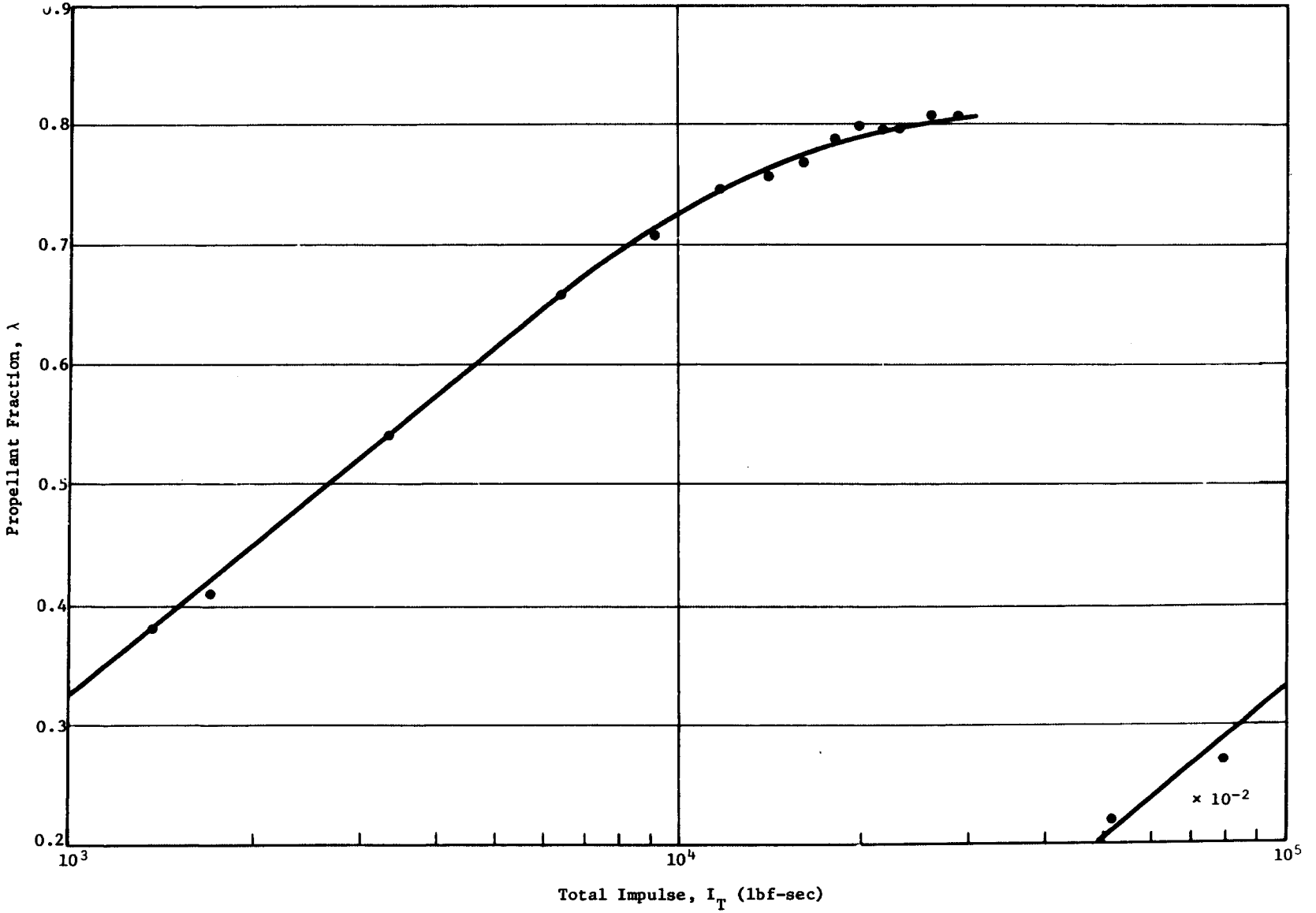


Figure C-4 λ vs I_T for State-of-the-Art Direct N_2H_4 Catalyst Blowdown Feed System

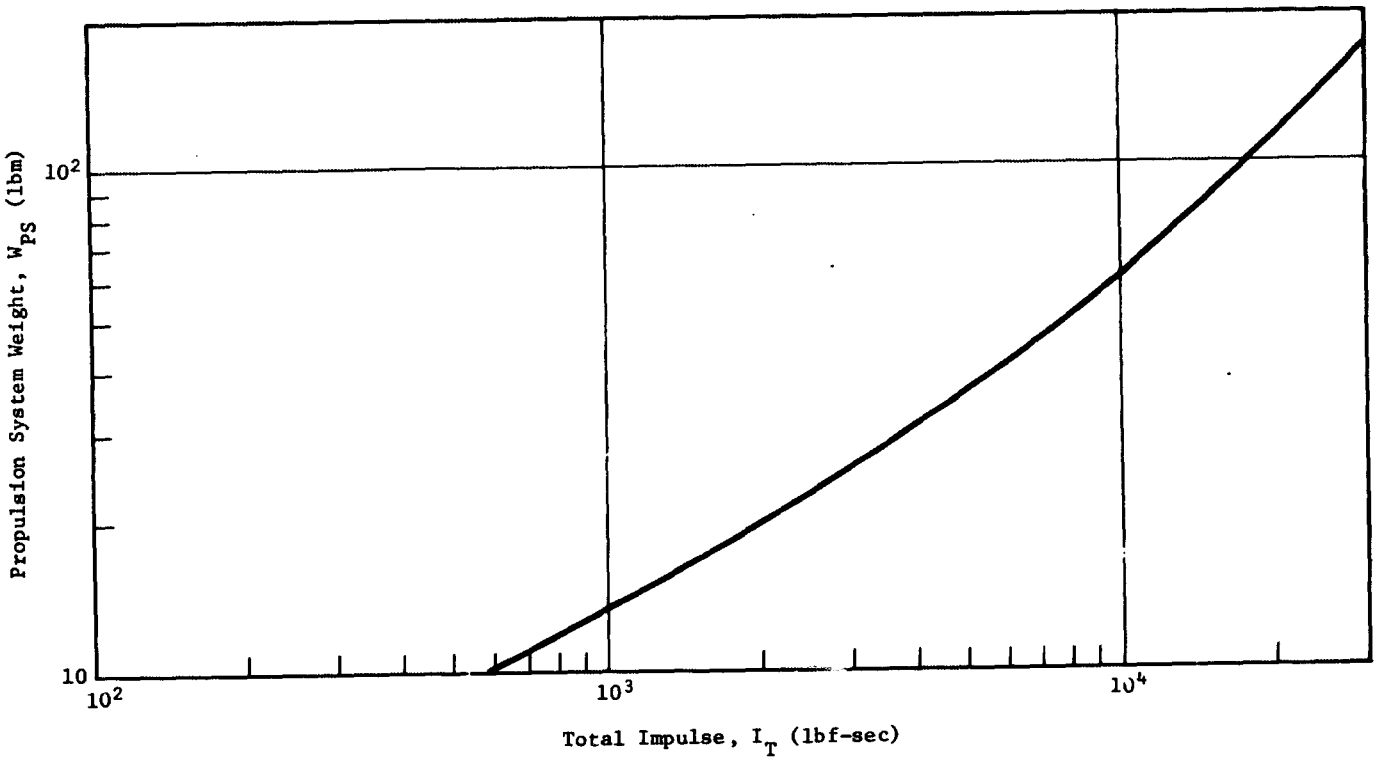


Figure C-5 I_T vs W_{PS} for State-of-the-Art Direct N_2H_4 Catalyst Blowdown Feed System

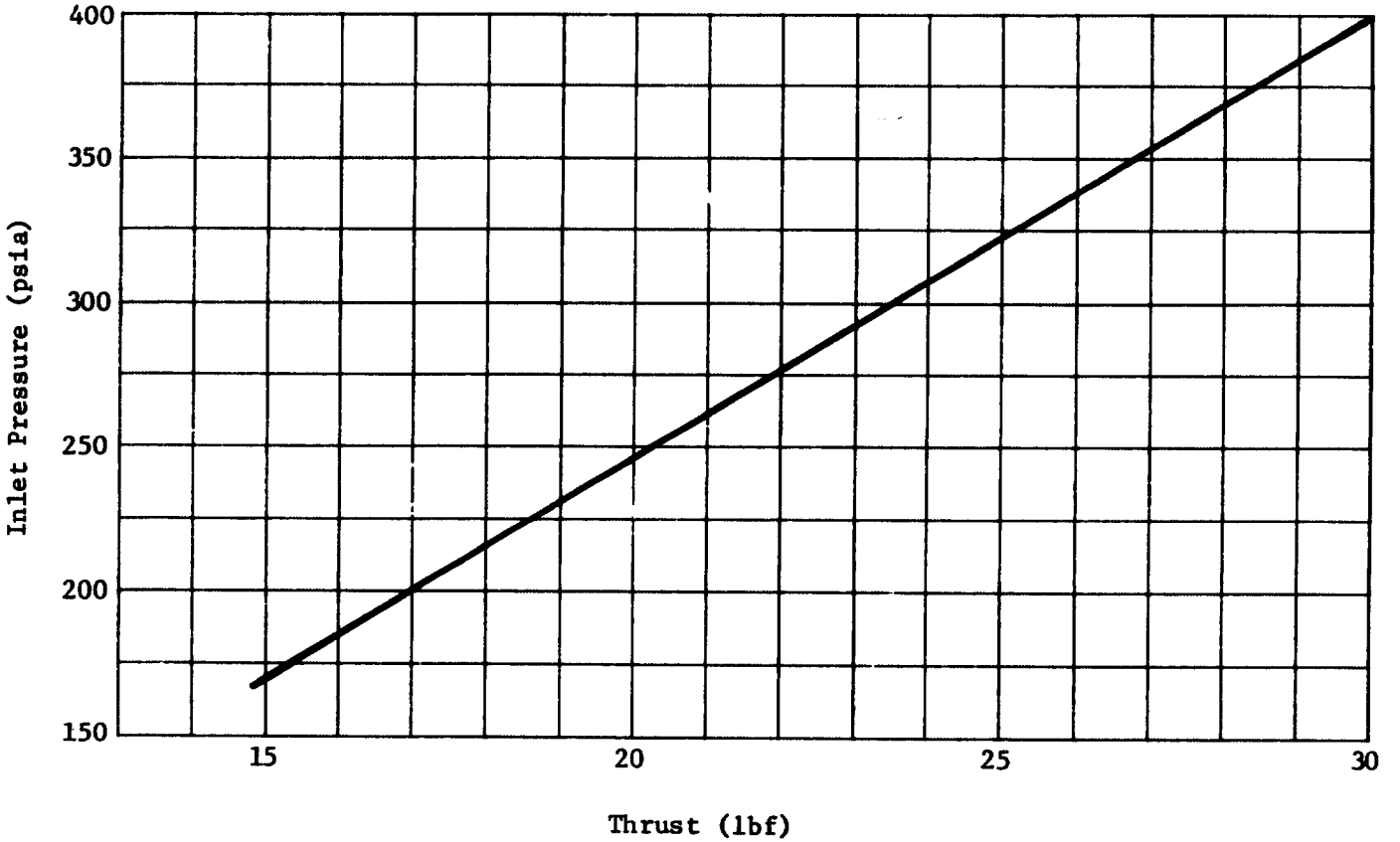


Figure C-6 Thrust vs Inlet Pressure N_2H_4 Direct Catalyst Thruster

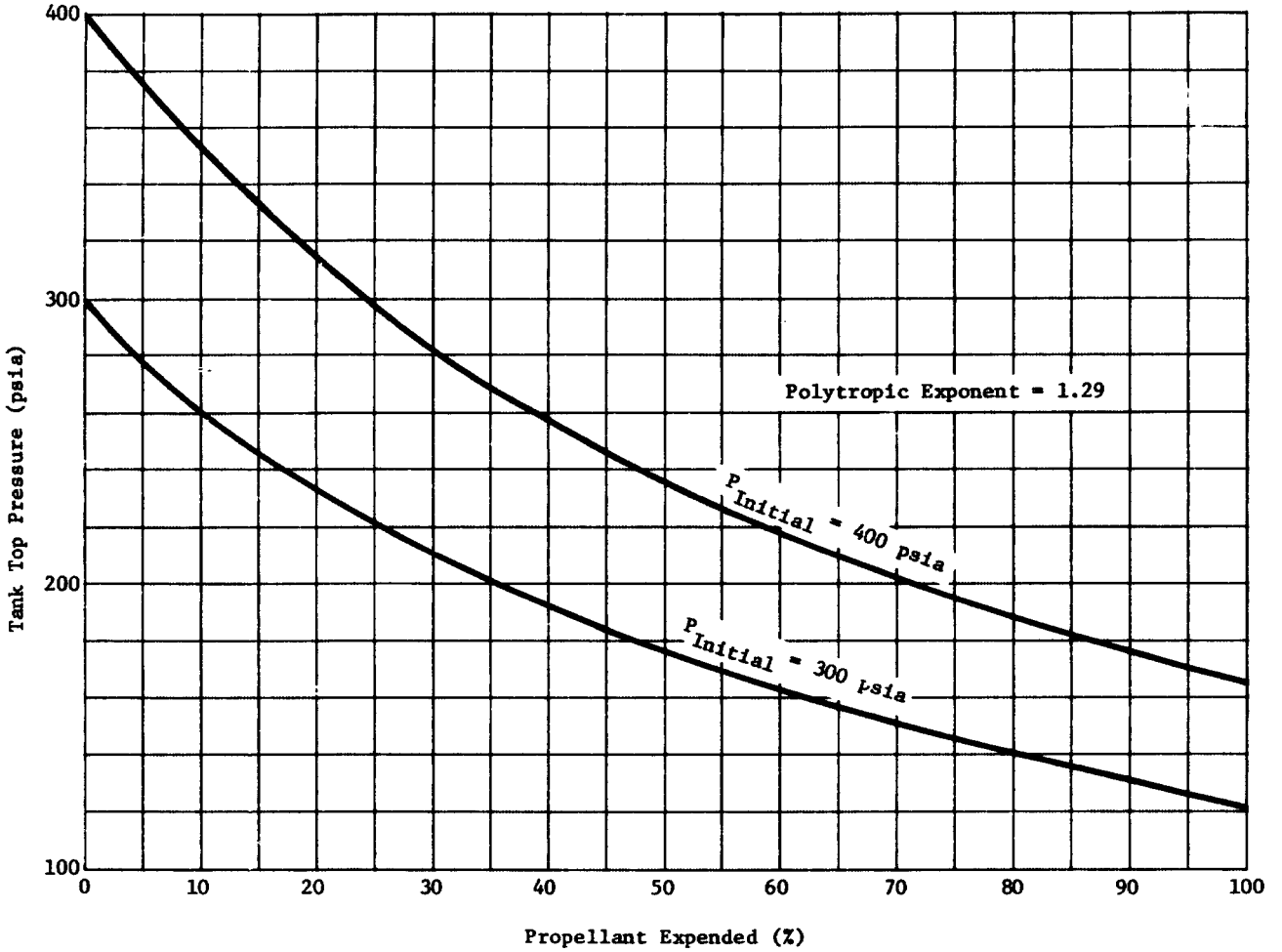


Figure C-7 N_2H_4 Tank Pressure as a Function of Propellant Expended (Blowdown)

3. Single Solid Propellant Rocket Motor

Solid rocket motor manufacturers were contacted to obtain recommended techniques for parametrically sizing solid rocket motors over a range of I_T from 500 to 25,000 lbf-sec. Computer programs for rough sizing and weight determinations were available; however they included proprietary information and therefore could not be furnished.

It was therefore decided that the reference probe deflection motor propellant characteristics and motor geometric relationships would form the basis for a parametric study of solid propellant rocket motors over the range of I_T noted. Figure C-8 presents the propellant and motor characteristics for a I_T of 1746 lbf-sec and Figure C-9 shows the geometric parameters studied as a function of I_T of the motor. For purposes of this study, the thrust coefficient and chamber pressure were assumed constant as was the delivered I_{sp} of the motor. As a result, the throat area $\left(A_T\right)$ varied directly as the thrust (F) varied, which in turn was directly proportional to the propellant weight $\left(W_P\right)$ and total impulse $\left(I_T\right)$.

Figure C-10 presents the propellant fraction (λ) as a function of I_T. This figure was constructed from representative solid motor data. Figure C-10 is used to relate W_{PS} as a function of I_T as presented in Figure C-11. Historically, it has been possible to achieve a higher propellant loading as the I_T of the motor increases, as is indicated in Figure C-12. This curve will tend to become asymptotic around propellant loadings of 0.85. The data presented is used in the calculation of motor dimensions as a function of I_T. Figure C-13 presents W_P as a function of I_T and is based on a I_{sp} of 287 lbf-sec/lbm. Figure C-14 presents F as a function of I_T and is based on the assumptions of propellant and motor characteristics previously discussed. Figure C-15 presents chamber length as a function of I_T and is based on W_P as a function of I_T, V_P/V_C as function of I_T, the geometric relationships of the reference vehicle motor, and the Figure C-9 schematic The motor chamber diameter $\left(D_c\right)$, nozzle length $\left(L_N\right)$, and throat area $\left(A_T\right)$as functions of I_T (Figures C-16, C-17, and C-18, respectively) are based on the same data sources as was used for the chamber length.

Performance		Weight Summary	
Total Impulse, lbf-sec	1746	Total Inerts, lbm	3.58
Average Thrust, lbf	318	Propellant, lbm	6.09
Average Pressure, psia	630	Total Motor, lbm	9.67
Delivered I_{sp}, lbf-sec/lbm	286.5	Mass Fraction	0.630
Duration, sec	5.48	Moment of Inertia	
Propellant Density, lb/in.^{3}	0.063	Roll	40 lb-in.^{2}
Reliability	0.998	Pitch or Yaw	84 lb-in.^{2}

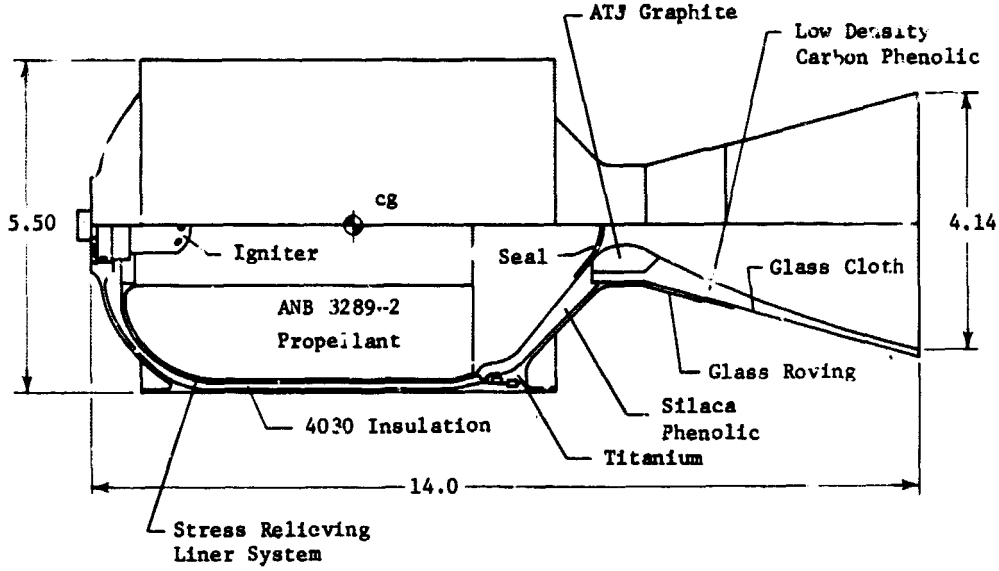
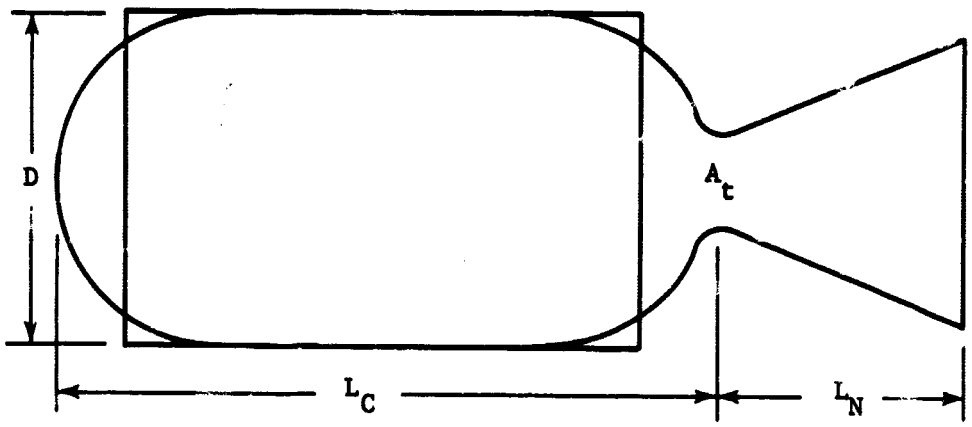


Figure C-8 Probe Deflection Motor



Nozzle Expansion Ratio = 40

Hemispherical Domes Assumed

Figure C-9 Solid Propellant Rocket Motor Geometry

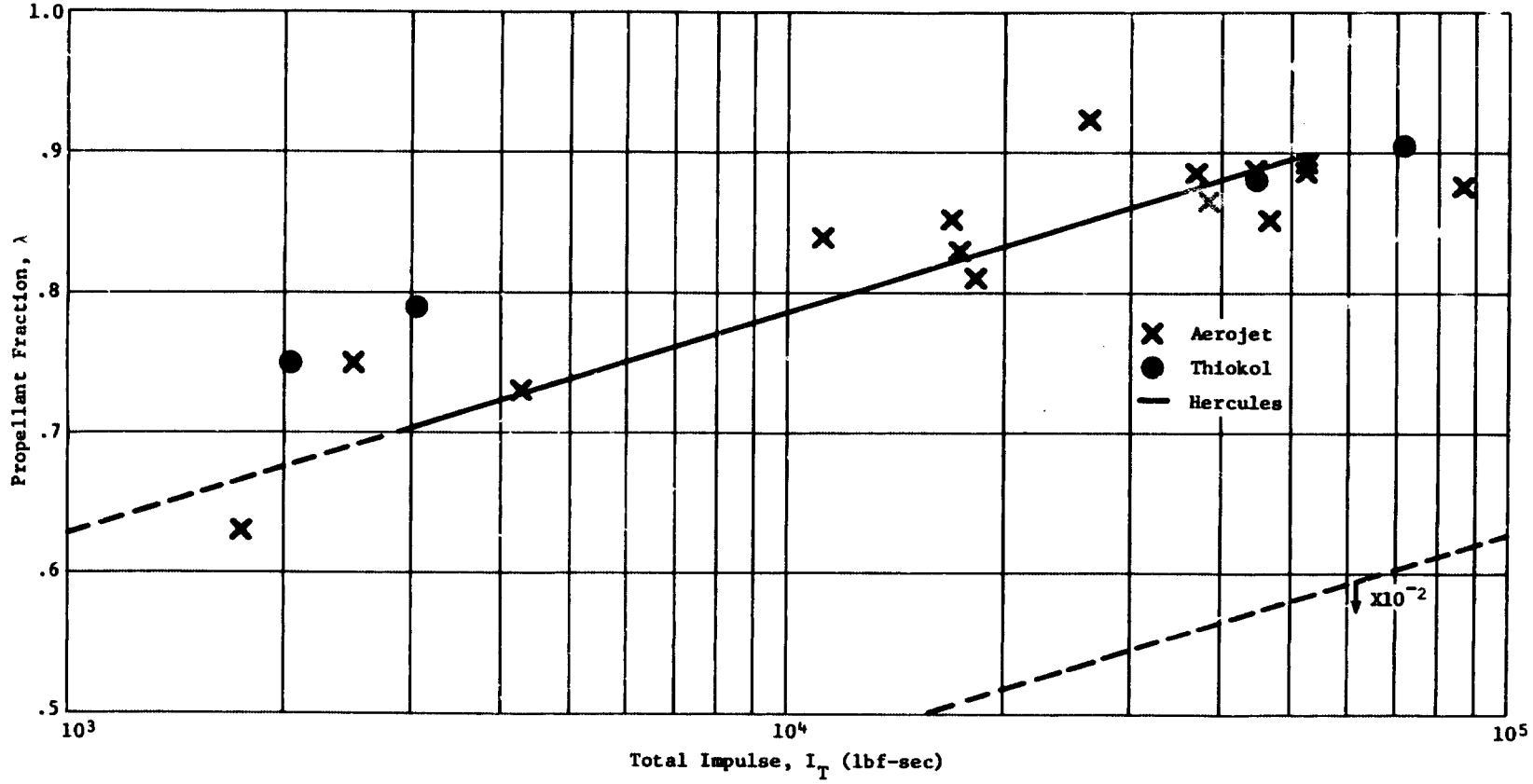


Figure C-10 λ vs I_T for Stage-of-the-Art Solid Propellant Motors

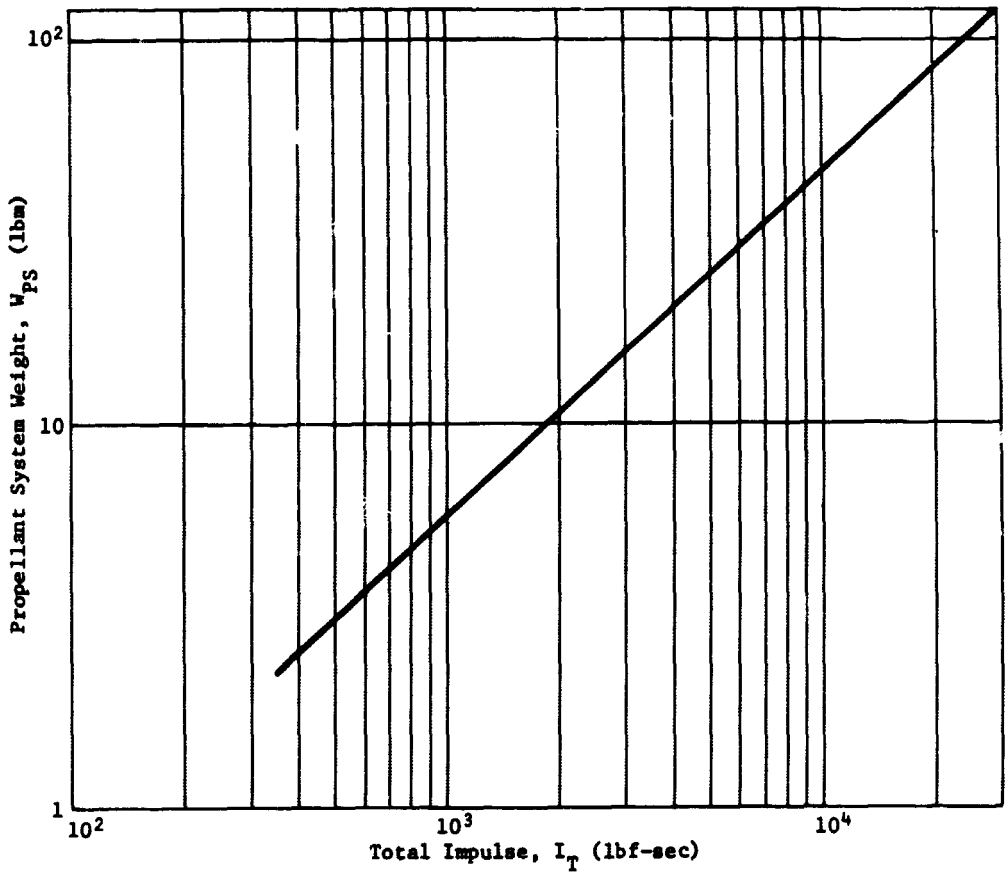


Figure C-11 I_T vs W_{PS} for State-of-the-Art Solid Propellant Motors

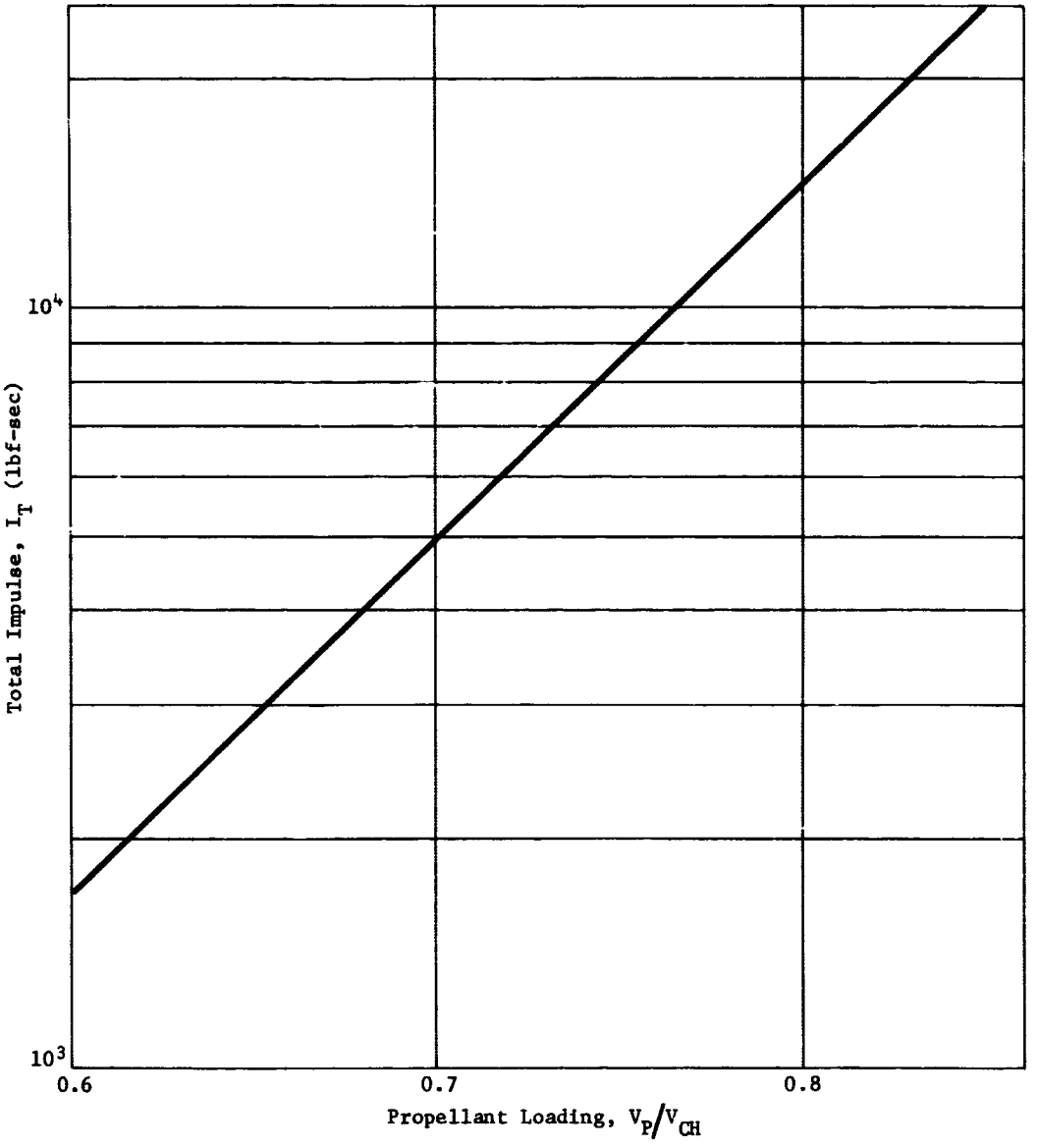


Figure C-12 Solid Propellant Motor Volumetric Solids Loading Fraction as a Function of Total Impulse

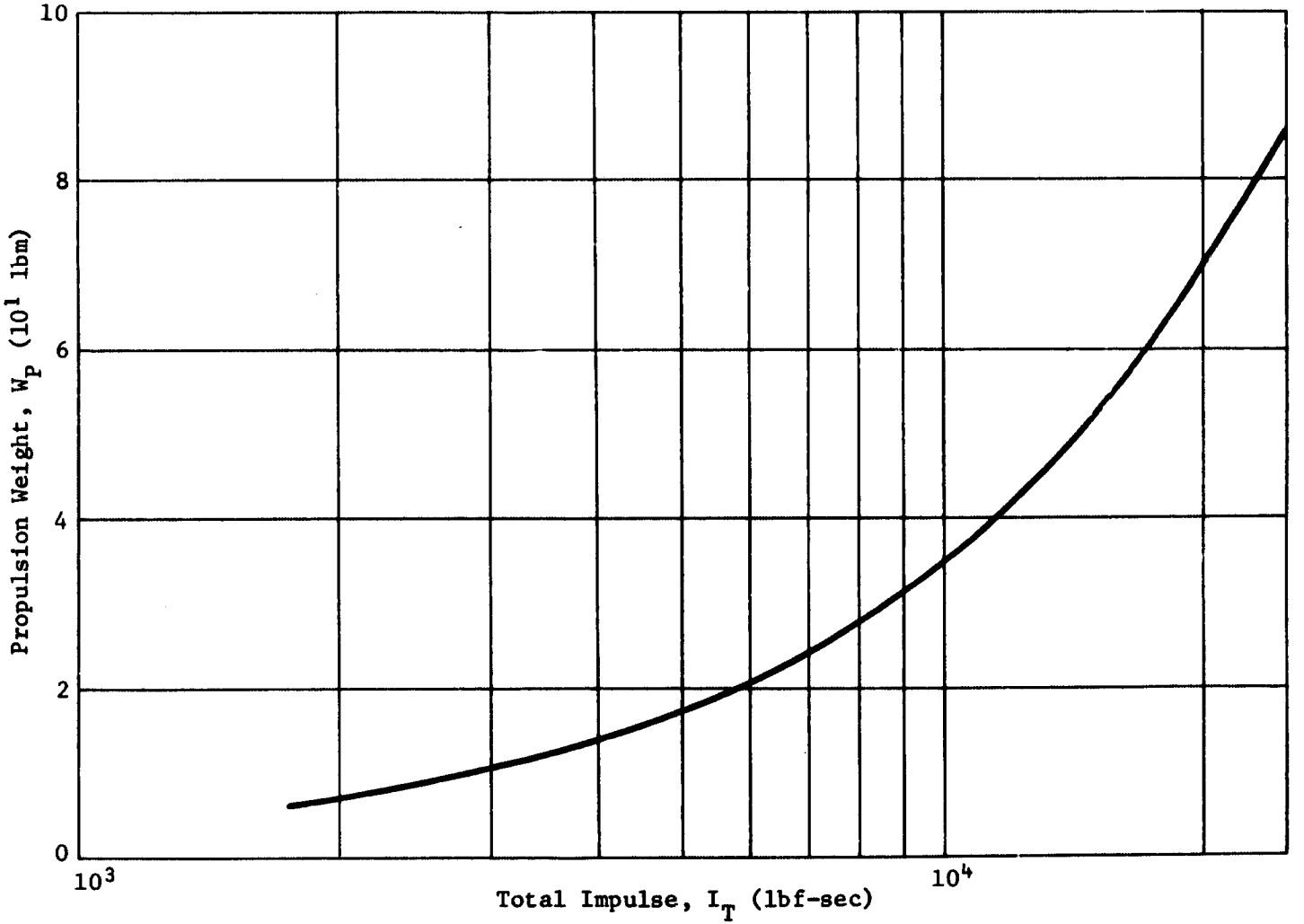


Figure C-13 Solid Rocket Deflection Motor W_P vs I_T

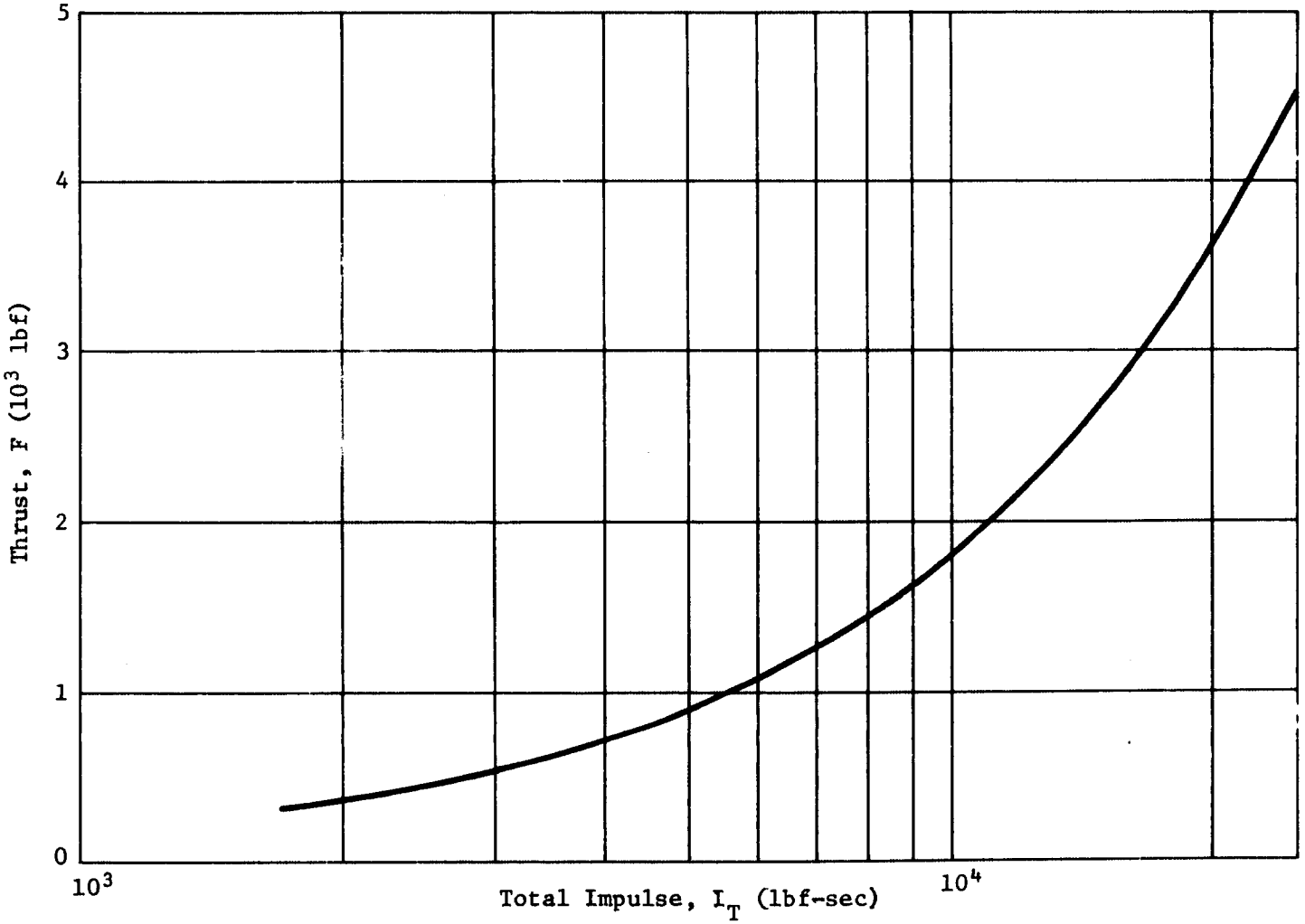


Figure C-14 Solid Rocket Deflection Motor F vs I_T

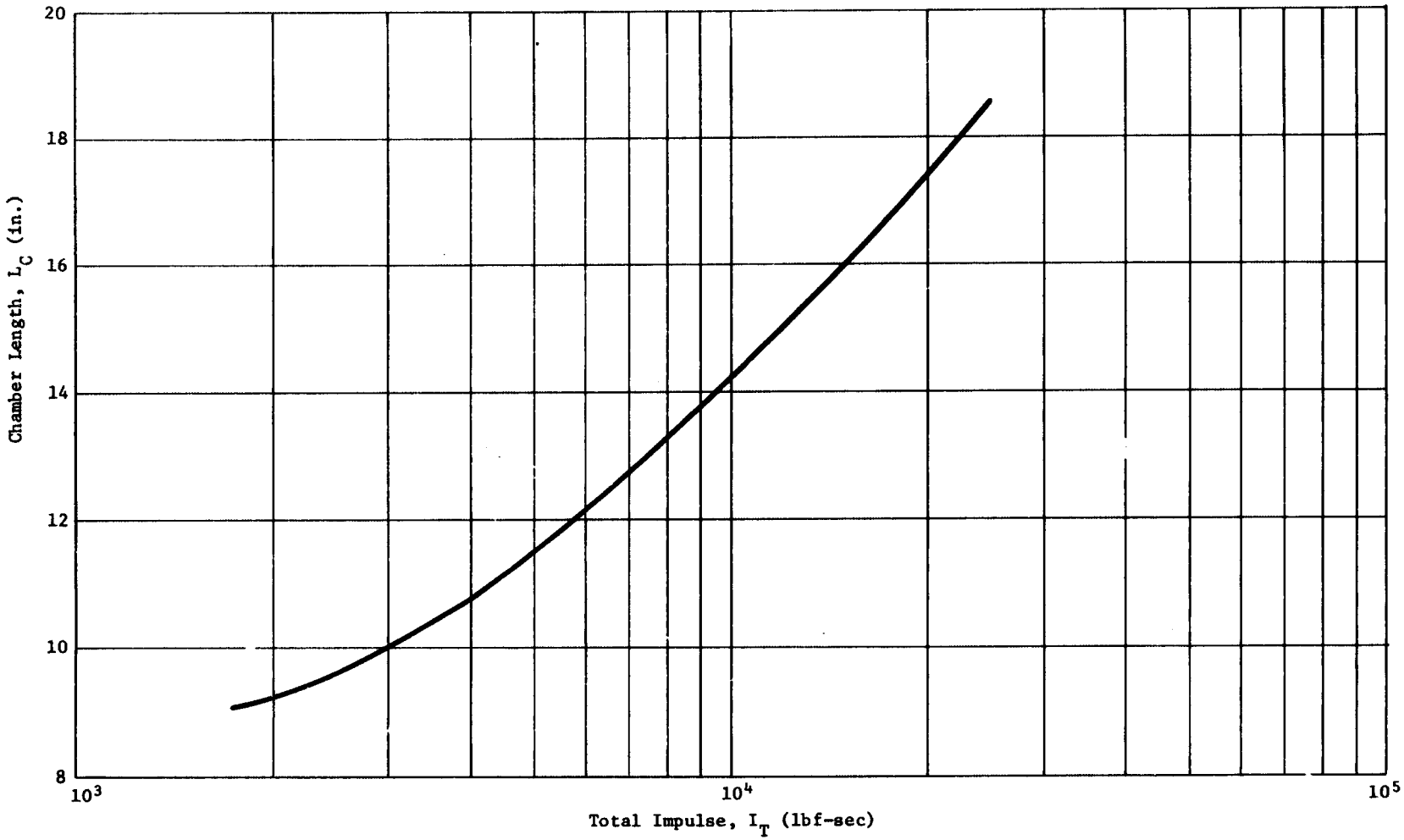


Figure C-15 Solid Rocket Deflection Motor L_C vs I_T

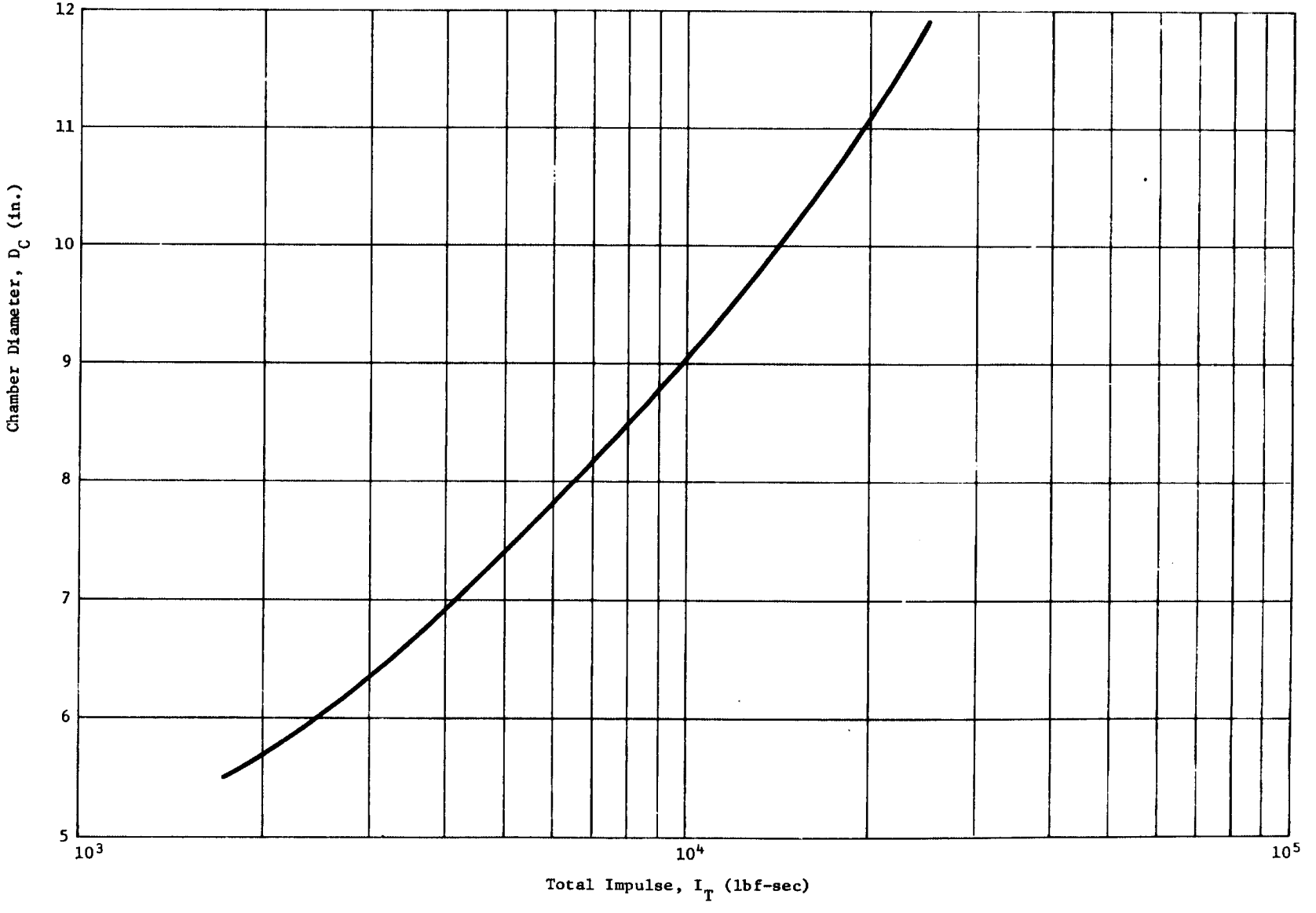


Figure C-16 Solid Rocket Deflection Motor D_C vs I_T

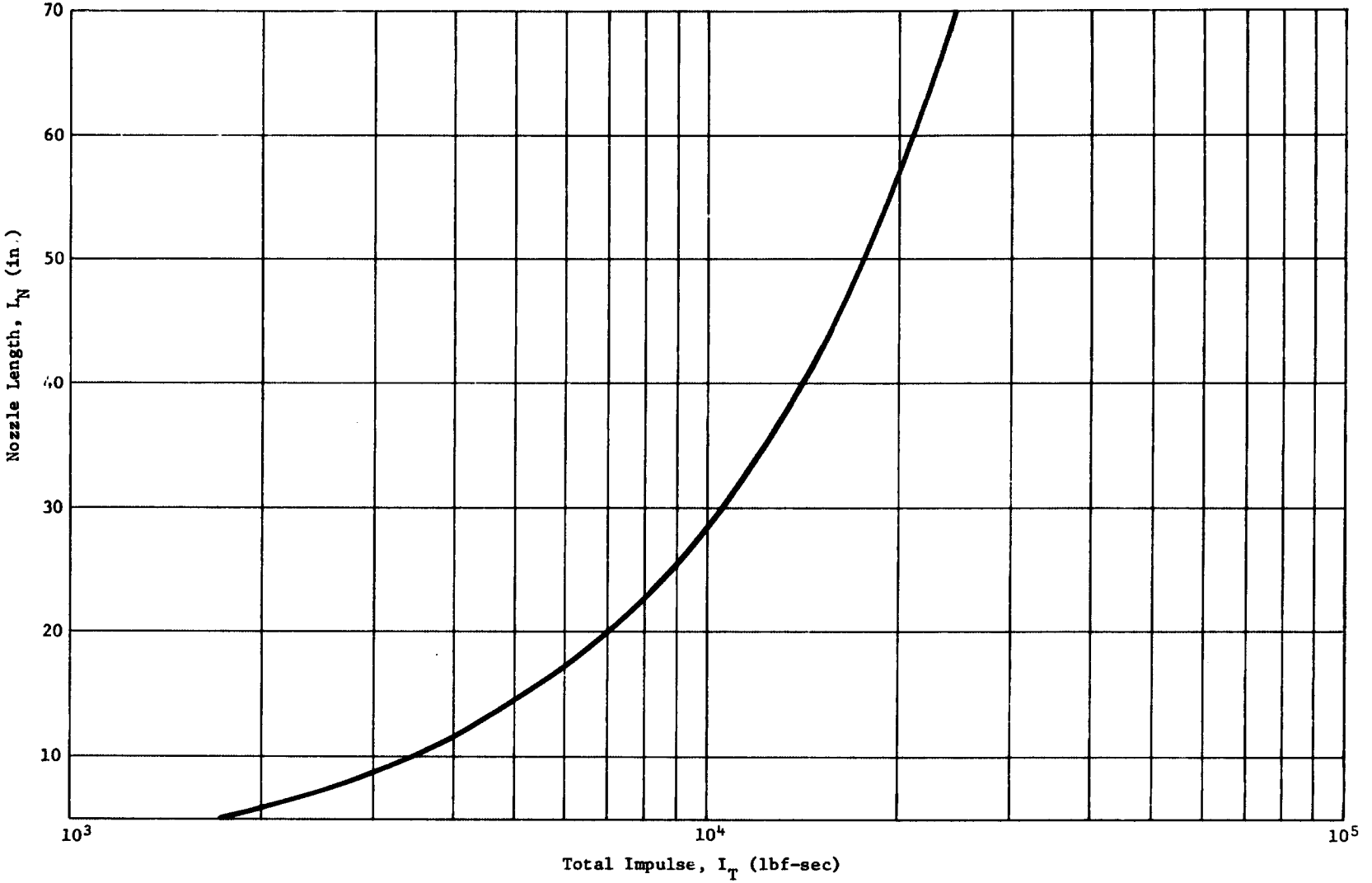


Figure C-17 Solid Rocket Deflection Motor L_N vs I_T

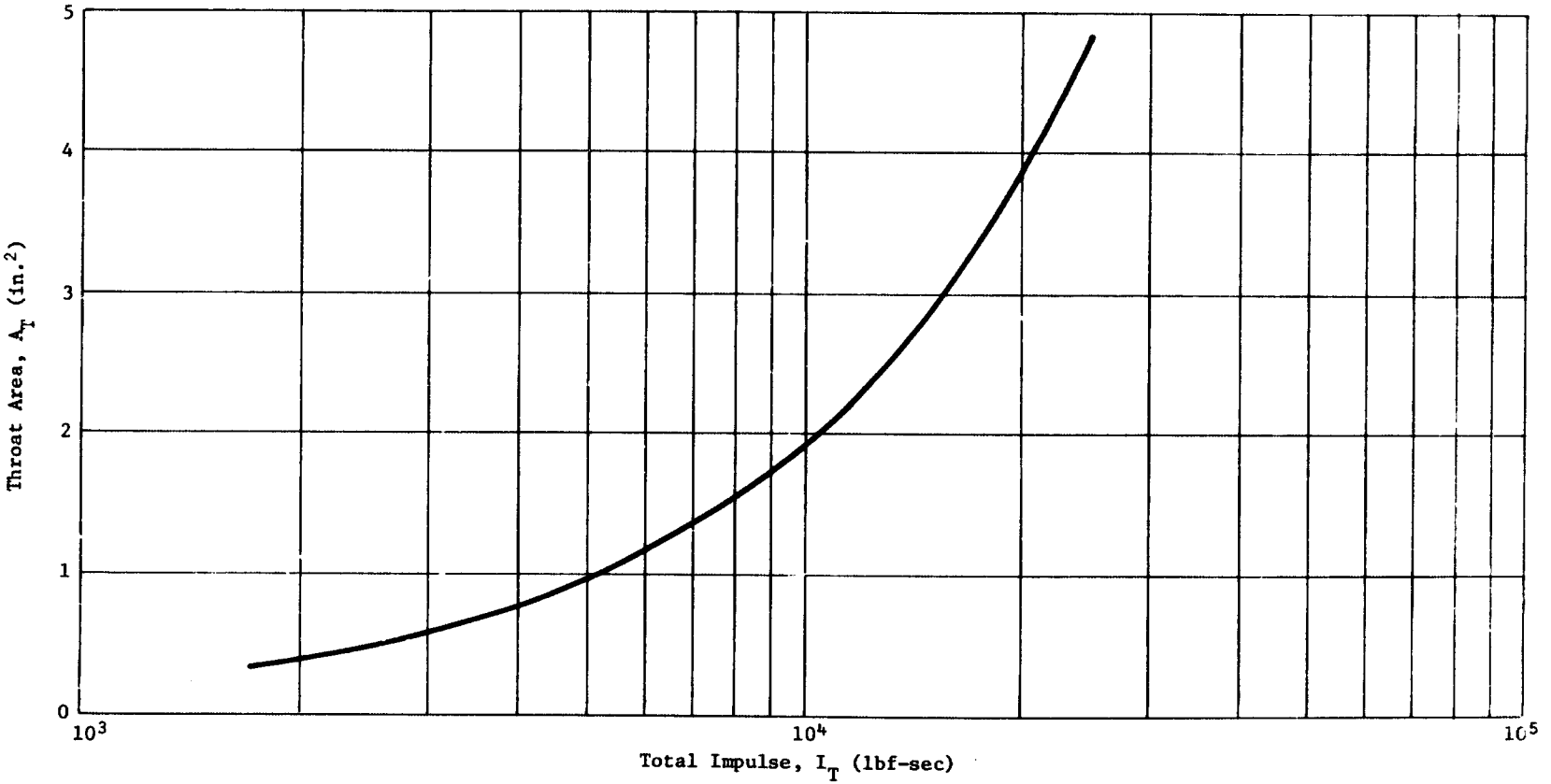


Figure C-18 Solid Rocket Deflection Motor A_T vs I_T

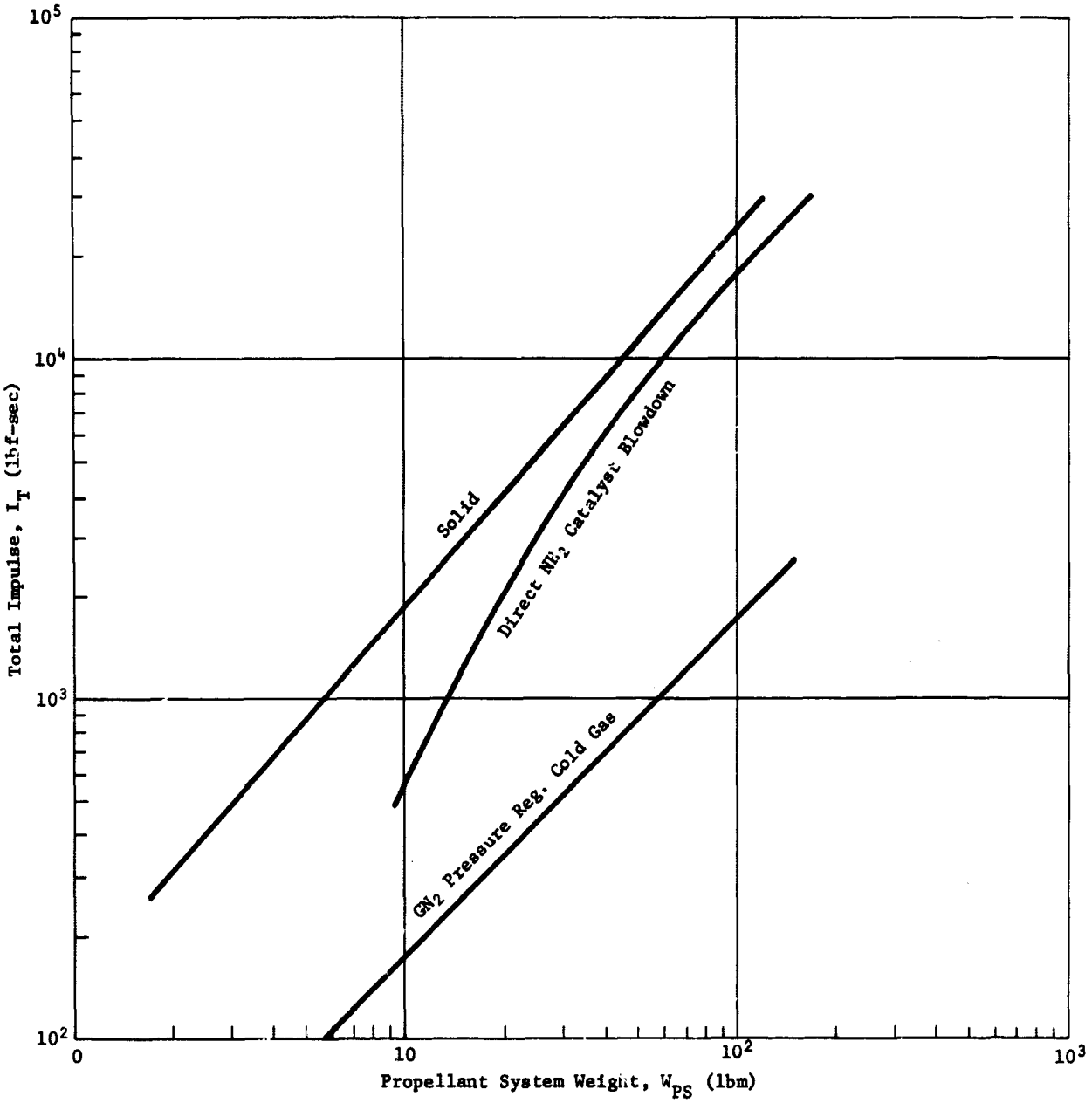


Figure C-19 I_T vs W_{PS} for State-of-the-Art Propulsion Systems

Figure C-19 presents a comparison of the three types of deflection propulsion systems studied using W_{PS} as a function of I_T. As can be seen, total impulse is not the sole consideration that prompted selection of a solid rocket motor for the deflection maneuver velocity increment. The exceptions could be associated with the high thrust levels and single thrust applications of the solid motor.

Reference:

1. Lee B. Holcomb: *Satellite Auxiliary - Propulsion Selection Techniques*. NASA, JPL TR 32-1505.

APPENDIX D

MONTE CARLO DEFLECTION DISPERSION ANALYSIS

E. D. Vogt

December 1971

A Monte Carlo computer program is used to compute the dispersions in communication and entry parameters caused by errors and uncertainties at the time of the deflection maneuver. The deflection maneuver itself is defined in detail in subsection IV.D.1 of Volume II of this report. A summary of the Monte Carlo technique is supplied in this appendix.

A. ERROR SOURCES

Two distinct types of errors are identified as causing dispersions from the nominal entry parameters. First, because of errors in the guidance and navigation process prior to the deflection maneuver, there are uncertainties in the spacecraft state at deflection. Secondly, there will be execution errors made by the spacecraft and probe in the implementation of the required maneuver.

1. Guidance and Navigation Uncertainties

Quantitative measures of the uncertainties in the spacecraft state at the deflection point are provided by the control and knowledge covariances* at that point. The control covariance P_c is a 6 × 6 matrix defined by

$$P_c = E\left[\left(X_{act} - X_{nom}\right)\left(X_{act} - X_{nom}\right)^T\right]$$

where E is the expeccation operator and X_{act} is the random variable vector describing the actual state (6 vector of position and velocity) of the spacecraft and X_{nom} is the nominal state of the spacecraft. P_c thus gives a measure of tne probabilistic deviation of the actual deflection state from the nominal state.

The generation of the control covariance proceeds as follows. It is assumed that the control errors result solely from errors at the last midcourse correction prior to deflection. A further assumption is made that the last midcourse correction is small enough that the execution errors are dominated by the knowledge errors at the time of the correction. A large *a priori* knowledge covariance is assumed at 25 days prior to the last midcourse maneuver when the tracking for that midcourse is initiated. The *a priori* knowledge covariance is reduced by processing simulated measurements for 25 days to determine the knowledge covariance at the midcourse. This covariance is then simply propagated (processing no measurements) over the last 13 days to generate the control covariance at the deflection point.

*The control and knowledge covariances referred to in this report correspond to the correlation matrix X of the actual deviation vector and the correlation rating E of the estimated errors in Battin's notation of Reference 1. General analytic details of the formulation of these mathematical tools may be found in this reference.

The knowledge covariance P_k at any point is defined mathematically as:

$$P_k = E\left[\left(X_{est} - X_{act}\right)\left(X_{est} - X_{act}\right)^T\right]$$

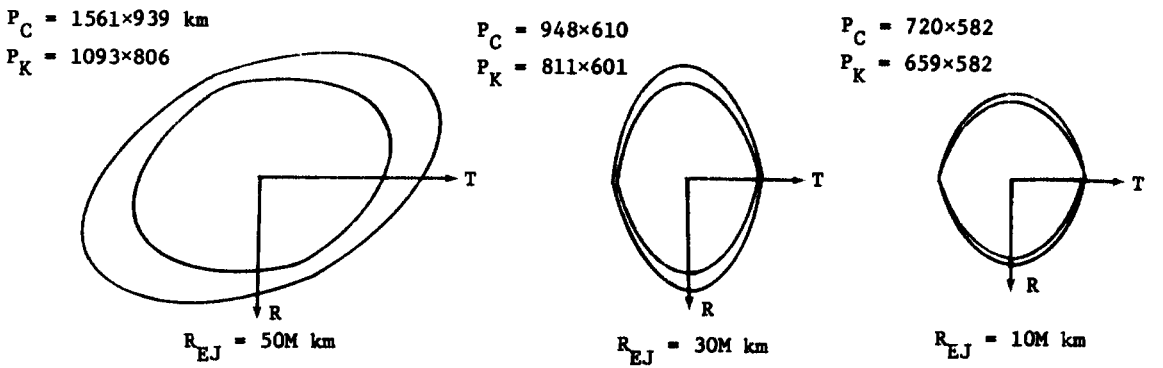
where X_{est} is the random variable representing possible estimated states if X_{act} is the actual state. Thus, P_k provides a quantitative measure of the estimation error to be expected at the time of deflection.

The knowledge covariance is generated similarly to the control covariance. Tracking begins at 38 days prior to deflection and measurement processing continues to one day prior to deflection. The knowledge covariance at that time (the deflection maneuver computation time) is then simply propagated to the nominal deflection time.

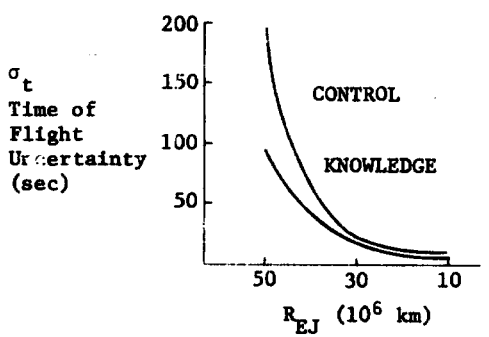
Thus, the knowledge and control uncertainties are really functions of the approach orbit determination (OD) processes. Since the orbit determination process is highly dependent upon the detection of the gravitational effects of Jupiter, the knowledge and control uncertainties decrease as the deflection maneuver is performed nearer Jupiter.

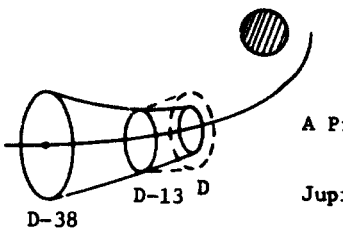
Figure D-1 presents a summary of the control and knowledge covariance computations. The pertinent data used in generating the uncertainties is supplied in Figure D-1C along with a pictorial representation of the process. Deflection radii of 10-, 30-, and 50-million kilometers were studied. These radii correspond to time intervals of approximately 8, 25, and 44 days before encounter. For any of the deflection radii, the tracking was initiated 38 days before deflection tracking through 25 days to generate the midcourse knowledge covariance. That covariance was then propagated forward to deflection to generate the deflection control covariance. Tracking was reinitiated on the midcourse knowledge covariance and carried through to one day prior to deflection. This was then simply propagated over the final day to generate the deflection knowledge covariance.

The dominant part of the deflection covariance matrice is the upper left 3 × 3 partition defining position uncertainties. This may be rotated into the standard RST coordinate system. Then the one sigma uncertainty in the spatial miss or the impact parameter B is defined in the TR plane as indicated in Figure D-1A. The one-sigma uncertainty in the S direction divided by the hyperbolic excess velocity produces the one-sigma time of flight uncertainty given in Figure D-1B.



A. SPATIAL MISS UNCERTAINTIES





B, TIME UNCERTAINTIES

A Priori Covariance σ_R = 5000 km
σ_V = 0.01 m/sec

Jupiter Ephemeris Uncertainty σ_R = 500 km

Doppler Noise: 0.3 mm/sec (1 min count)

Station Location Errors: σ_{RS} = 1.5 m
σ_L = 3.0 m
ρ_L = 0.97

C. GROUNDRULES

Figure D-1. Knowledge and Control Uncertainties at Deflection

The net effect of decreasing the deflection radius on the knowledge and control covariances is evident. Decreasing the deflection radius from 50- to 30-million kilometers reduces the uncertainties by approximately one-third. Decreasing the deflection radius from 30 to 10 million kilometers produces a decrease in uncertainties of approximately one-fourth.

An intuitive feeling for the exact use of knowledge and control covariances may be gained by referring to section B which describes the analytical technique used in the Monte Carlo dispersion analysis program.

Execution Errors

The second source of errors analyzed results from execution errors made in implementing the actual maneuvers required. The types of maneuvers encountered in the three modes identified earlier are:

1) Probe deflection maneuver;

2) Spacecraft deflection maneuver;

3) Probe release and/or orientation.

The error models used to analyze each of these maneuvers are described in the following paragraphs.

The purpose of the probe or spacecraft deflection maneuvers is to add a commanded velocity increment $\underline{\Delta v}$ to the current probe or spacecraft state. The actual velocity increment imparted to the body will differ from the commanded value by an amount $\underline{\delta \Delta v}$ that represents the contribution due to execution errors. The execution error model used in this study is defined by four independent error sources.

The first error source is called the proportionality error and is in the direction of the velocity correction, $\underline{\Delta v}$, with magnitude determined by the proportionality factor, k:

$$\underline{\delta \Delta v_K} = k \, \underline{\Delta v}$$

A second error source in the direction of $\underline{\Delta v}$ but independent of its magnitude, is the resolution error, s, that corresponds to a thrust tailoff error from the thrusters:

$$\underline{\delta \Delta v}_s = \frac{s}{\Delta v} \underline{\Delta v}$$

The other error sources are pointing direction errors. The first of these is a pointing error angle, α, measured in a plane parallel to the ecliptic plane (for Jupiter missions, approximately the orbital plane), and along a vector orthogonal to the velocity correction vector, $\underline{\Delta v}$. If $\underline{i}$, $\underline{j}$, $\underline{k}$ form the unit triad in the ecliptic system, then for small angles, α, the velocity error caused by the in-plane pointing error is given by

$$\underline{\delta \Delta v}_\alpha = c \, \Delta v \, \alpha \left[\Delta v_y \, \underline{i} - \Delta v_x \, \underline{j} \right]$$

where $\underline{\Delta v} = \Delta v_x \, \underline{i} + \Delta v_y \, \underline{j} + \Delta v_z \, \underline{k}$ and $c = \left(\Delta v_x^2 + \Delta v_y^2 \right)^{-1/2}$. The second pointing error, called the out-of-plane error defines the velocity error that is orthogonal to both $\underline{\delta \Delta v}_\alpha$ and the velocity increment vector, $\underline{\Delta v}$. Again, for small angles, β, the velocity error resulting from this pointing error, referenced to the ecliptic system, is given by

$$\underline{\delta \Delta v}_\beta = \beta c \left[\Delta v_x \, \Delta v_z \, \underline{i} + \Delta v_y \, \Delta v_z \, \underline{j} - \frac{1}{c^2} \underline{k} \right]$$

Then the total execution error resulting from a proportionality error, k, resolution error, s, and pointing errors, α and β, is given by the sum of these errors

$$\underline{\delta \Delta v} = \underline{\delta \Delta v}_k + \underline{\delta \Delta v}_s + \underline{\delta \Delta v}_\alpha + \underline{\delta \Delta v}_\beta$$

The mathematical model used to describe velocity increment errors is the same for either spacecraft or probe. The individual magnitudes of the execution error sources, k, s, α, and β, may be varied, however, for individual characteristics of the probe or spacecraft. In general, the Pioneer pointing accuracy is 5% of the angle rotated off Earth lock, the TOPS error is considered to be 1 degree (3σ).

The probe release and/or orientation error is essentially involved with simply aligning the probe axis for its zero degree relative angle of attack at entry. This corresponds to the maneuver by which the probe is released from the spacecraft in the Mode 3/ Deflect Spacecraft sequence or to the probe self-reorientation maneuver in the Mode 1/Deflect Probe scheme. The current mathematical model for this type of maneuver is based on a single pointing error referenced to the desired direction.

Let $\underline{u}_D$ denote the desired direction for the probe axis. Define

$$\underline{v}_1 = \frac{\underline{r} \times \underline{u}_A}{|\underline{r} \times \underline{u}_A|}$$

$$\underline{v}_2 = \underline{u}_A \times \underline{v}_1$$

Then $\underline{v}_1$ and $\underline{v}_2$ are unit vectors in the plane normal to the desired direction $\underline{u}_A$. An arbitrary unit vector in that plane may then be written.

$$\underline{x} = \underline{v}_1 \cos \theta + \underline{v}_2 \sin \theta$$

where θ is a random variable chosen from a uniform distribution over the interval $(0, 2\pi)$. If the orientation pointing error is to be of magnitude δ, then the actual pointing direction resulting from the error is given by

$$\underline{u}_A = \underline{u}_D \cos \delta + \underline{x} \sin \delta$$

ANALYTICAL TECHNIQUE

A Monte Carlo technique is used to convert the errors associated with the deflection maneuver into dispersions in the critical mission parameters. The Monte Carlo procedure will be defined in detail for the Mode 1/Deflect Probe deflection scheme. The modifications for the Mode 2/Shared Deflection and Mode 3/Deflect Spacecraft schemes are then easily explained.

The Monte Carlo technique used in this study consists of generating a large number of sample probe and spacecraft trajectories consistent with assumed statistics of the knowledge and control uncertainties and execution errors. These trajectories are then propagated to certain mission time points (probe acquisition by spacecraft, entry, and selected intermediate points), and the critical mission parameters are evaluated. Because each sample spacecraft and probe trajectory will differ from the nominal (errorless) ones, the critical parameters will also differ. The data in dispersions in critical mission parameters are then analyzed by empirical formulas, assuming normal distributions

to establish mean and three sigma deviations in each critical parameter for each selected time point. The computational flow, outlined in Figure D-2, may be broken up into three main components that are discussed in detail.

Preliminary Computations

The preliminary computations generally comprise the determination of the nominal trajectories and preparation for the selection of the perturbed trajectories. The nominal deflection maneuver is first computed, which for the given hyperbolic excess velocity (equivalently the given launch date/arrival date) and desired deflection radius satisfies the desired entry conditions and communication geometry. The knowledge and control covariances, P_k and P_c, are then computed from an orbit determination program in which the procedure described in section A is used. Finally, the execution error uncertainties, σ_k, σ_s, σ_α, σ_β, σ_δ, are selected on the basis of the spacecraft used, the nominal geometry involved (such as the rotation off Earth lock required to implement the maneuver), and the magnitude of errors requiring analysis.

The Sampling Procedure

The bulk of the dispersion analysis is concerned with the generation of the statistically consistent ensemble of spacecraft-probe trajectory samples. For each sample, the first problem (listed in Figure D-2) is to generate reasonable deviation vectors, δX_k and δX_c, from the knowledge and control covariances, P_k and P_c. This sampling is done as follows.

Let P represent P_k or P_c. Then, since P is positive definite, it may be diagonalized.

$$P = T^T D T$$

where $D = \text{diag}\,(d_1^2, d_2^2, \ldots, d_6^2)$, T is the orthonormal matrix of the eigenvectors of P, and the superscript T denotes the matrix transpose operation. The elements of D are written as squares to indicate they are necessarily positive numbers.

I. PRELIMINARY COMPUTATIONS

A. Read in nominal spacecraft deflection state X_{nom} desired entry angle, γ, and lead angle, λ, knowledge and control covariance matrices, P_k and P_c, execution error model uncertainties, σ_k, σ_s, σ_α, σ_β, σ_δ.

B. Compute nominal deflection maneuver and parameters

II. SAMPLING PROCEDURE

Generate large number ($N \geq 100$) of sample off-nominal cases. For each case --

A. Sample knowledge and control covariances to obtain the deviation vectors, δX_k and δX_c.

B. Form the actual and estimated spacecraft states

$$X_{act} = X_{nom} + \delta X_c$$

$$X_{est} = X_{act} + \delta X_k$$

C. Compute the commanded velocity increment, Δv_c, based on the estimated state, X_{est}, and the desired γ and λ.

D. Sample the execution errors, generate the resulting error in velocity increment, Δv. Compute the post-deflection probe state as

$$Y_{act} = X_{act} + \begin{bmatrix} -\Delta\bar{v}_c \\ \bar{0} \\ -\delta\bar{\Delta}v \end{bmatrix}$$

$$Y_{est} = Y_{act} + \delta X_k + u$$

E. Compute the desired orientation of the probe at entry, $\underline{u}_a$, using Y_{est}. Generate a sample orientation error and compute the corresponding actual probe orientation, $\underline{u}_A$.

F. Propagate the actual probe and spacecraft to probe entry using conic formula. Store the dispersions in critical mission parameters at each timepoint.

III. STATISTICAL ANALYSIS OF DISPERSION DATA

Using the dispersion data generated for each sample case, compute the mean and standard deviaiton for each critical mission parameter for each selected timepoint.

Figure D-2 Computational Flow Chart of Monte Carlo Analysis Program

T defines a transformation from the original Cartesian coordinate system to a new system in which the covariance matrix is uncorrelated, thereby allowing the individual components to be sampled independently. A vector random variable from a distribution of mean zero and covariance, D, is given by

$$Z = \left(e_1 d_1, e_2 d_2, \ldots , e_6 d_6\right)^T$$

where each e_i is a scalar random variable sampled from a normal distribution of mean zero and standard deviation unity. The e_i are computed from the formula

$$e_i = \sqrt{-2 \ln \alpha_i} \cos\left(2\pi \beta_i\right)$$

where α_i and β_i are random numbers generated from a uniform distribution over the interval (0, 1). The correlated deviation vector in the original Cartesian coordinate system may now be computed using the transformation matrix, T, as

$$\delta X = T \delta Z$$

Therefore, for each sample case, the knowledge and control covariances may be sampled as above to produce knowledge and control state deviation vectors, δX_k and δX_c. The "actual" spacecraft state for the sample is given by

$$X_{act} = X_{nom} + \delta X_c.$$

The "estimated" state of the spacecraft at deflection is given by

$$X_{est} = X_{act} + \text{---}_k.$$

Furthermore, at the end of a large number of samples ($N \geq 100$), the ensemble of deviations, δX_c and δX_k, should obey the empirical formulas

$$E\left(\delta X_c \, \delta X_c^T\right) \rightarrow P_c \text{ as } N \rightarrow \infty$$

$$E\left(\delta X_k \, \delta X_k^T\right) \rightarrow P_k \text{ as } N \rightarrow \infty.$$

These approximations are checked at the end of the sampling process to ensure that a statistically consistent set of data has been generated.

Having obtained the estimated state of the spacecraft for a sample, the next task is to determine the commanded velocity increment, Δv_c, to be added to the probe at deflection. The vector, Δv_c, is computed as a function of the estimated spacecraft state at deflection, the desired probe flight path angle at entry, γ_c, and the desired lead angle, λ_c. The lead angle is the angle between the radius vector to the probe at entry and the radius vector to the spacecraft at the time of entry. The lead angle is negative when the probe leads the spacecraft. The deflection velocity is determined by iterating on the value of $\Delta\theta$, the true anomaly increment of the probe in going from deflection to entry. The true anomaly of the probe at entry, f_{PE}, can be expressed as:

$$f_{PE} = f\ \gamma_c, R_{EJ}, \Delta\theta, R_A$$

where R_{EJ} is the radius of the bus at deflection and R_A is the radius of the atmosphere. f_{PE}, R_{EJ}, $\Delta\theta$, R_A are used to compute the time of flight, T, from deflection to probe entry using the universal form of Kepler's equation as presented in Reference 1. The spacecraft state is then propagated forward for time T, again using the universal form of Kepler's equation, and the angle, λ, is computed from the state of the spacecraft and the state of the probe at time T. The angle, λ, is compared with the desired λ_c and the $\Delta\theta$ which causes λ to be within 0.01 degrees of λ_c, is found. Since the orbital elements of the probe are known, the required deflection velocity vector may be calculated. The commanded deflection velocity is in the spacecraft plane of motion.

The deviations in the implemented deflection velocity from the commanded are generated using the model described in subsection A2. This model assumes the implementation error is given by three sources: proportionality error, K; resolution error, S; and pointing angle errors, α, β. These errors are assumed uncorrelated and normally distributed. The standard deviation of each error σ_K, σ_S, σ_α, σ_β is input to the program. The error used in each Monte Carlo sample is generated by

$$K, S, \alpha, \beta = e_1\sigma_K, e_2\sigma_S, e_3\sigma_\alpha, e_4\sigma_\beta$$

where each e_i is a scalar random variable sampled from a normal distribution of mean zero and standard deviation unity. The execution error, $\delta\Delta v$, is then the sum of these errors.

The actual state of the probe at deflection is then the actual position vector of the probe and the sum of velocity of the spacecraft and the actual deflection, Δv, given to the probe.

$$Y_{act} = X_{act} + \begin{bmatrix} \underline{0} \\ \Delta v_c + \delta \Delta v \end{bmatrix}$$

Now that the actual states of the probe and spacecraft are known, the time histories of these two point masses may be computed using conic models.

The attitude of the probe is a crucial parameter, however, as this determines such mission critical parameters as angle of attack at entry and probe aspect angle. Using the nominal trajectory, the desired probe attitude is computed, $\underline{u}_\alpha$. A pointing error caused by imperfections in the attitude control system is computed in a similar statistical fashion as described above. Once the "actual" probe axis is computed, it is assumed to hold that orientation throughout the mission. No errors are added to the spacecraft axis since it is assumed that the spacecraft can hold the Earth lock with essentially no error.

For each sample probe and space trajectory and probe attitude, the critical entry and communication parameters may be computed as functions of time. The resulting collection of data must then be analyzed by the techniques described in the next subsection.

Statistical Analysis of Dispersion Data

The empirical computation of the standard deviations of scalar parameters such as entry angle, lead angle, or lead time may be computed in the following way. Let α_i be the value of any such parameter for the i^{th} case. Suppose that there are N samples to be analyzed. Then the mean and standard deviation of the distribution of α are given by

$$\bar{\alpha} = \frac{1}{N} \sum_{i=1}^{N} \alpha_i$$

$$\sigma_\alpha^2 = \left[\sum_{i=1}^{N} \frac{\alpha_i^2}{N} \right] - \frac{\bar{\alpha}^2}{N}$$

These formulas must be extended for vector quantities. The probe entry site dispersions are given in terms of the two vectors of latitude and longitude (LAT, LON). The spacecraft-probe look direction is conveniently described in terms of the two vectors of cone angle and clock angle (CA, CLA) referenced to Earth and Canopus. Equivalently, these dispersions may be defined in terms of cone angle and cross-cone angle (CA, CCA).

Let Z_i represent the vector describing the actual values achieved for a vector quantity on the i^{th} sample. Then, the vector of mean values and the covariance matrix describing uncertainties and correlations of the vector are given by the formulas

$$\bar{Z} = \frac{1}{N} \sum_{i=1}^{N} Z_i$$

$$P_z = E(ZZ^T) - E(Z)E(Z)^T$$

$$= \frac{1}{N} \left[\sum_{i=1}^{N} ZZ^T \right] - \frac{\bar{Z}\,\bar{Z}^T}{N}$$

These formulas are used to compute the covariance matrices of the critical mission vector quantities as well as to reconstruct the original knowledge and control covariances from the deviation vectors generated.

For the entry stie dispersions (LON, LAT) and the spacecraft-probe look directions (CA, CLA) or (CA, CCA), the 2 × 2 covariances are further analyzed. Let any such covariance matrix be denoted P. Then since P is positive definite it may be diagonalized to produce

$$P = TDT^T = T \begin{bmatrix} \lambda_A & 0 \\ 0 & \lambda_B \end{bmatrix} T^T$$

Where λ_A and λ_B are the (positive) eigenvalues of the covariance matrix P, and T is the orthonormal matrix of the eigenvectors of P. Let

$$T = \begin{bmatrix} t_A \\ - \\ t_B \end{bmatrix}$$

Then t_A is the unit eigenvector associated with the eigenvalue, λ_A. Then the angle between the vector, t_A, and the u_x unit vector (longitude direction for (LON, LAT), cone angle direction for (CA, CLA) or (CA, CCA) is defined by

$$\theta = \cos^{-1}\left(t_A \cdot u_x\right) \quad 0 \leq \theta \leq \pi$$

The uncertainty ellipse may now be easily constructed: λ_A represents one semiaxis; λ_B the other.

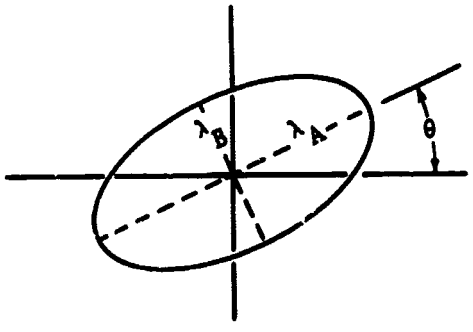


Figure D-3 Two-Dimensional Uncertainty Ellipse

Procedures for Alternative Deflection Modes

The procedure for Mode 1/Deflect Probe has been described in detail. A comparison of the procedures for the Mode 2/Shared Deflection and Mode 3/Deflect Spacecraft is provided in Figure IV-3 of Volume II of this report.

For each sample in each mode, the initial task is to determine the control and knowledge deviations, δX_c and δX_k, by sampling the control and knowledge covariances. The actual state of the spacecraft is then defined by $X_{act} = X_{nom} + \delta X_c$; the estimated state of the spacecraft is $X_{est} = X_{act} + \delta X_k$, where X_{nom} is the nominal spacecraft deflection state.

In Mode 1/Deflect Probe the estimated state, X_{est}, is used to determine the commanded probe deflection, Δv. This velocity increment is then degraded by an execution error, $\delta\Delta v$, determined by sampling from possible execution errors. The probe axis orientation throughout the mission is computed as the nominal orientation corrupted by an orientation pointing error, δ. The deflection states for the probe and spacecraft are then propagated to a series of time points at which the sample deviations are recorded. These dispersions are then analyzed to yield mean and standard deviation values.

In the study of the Mode 1/Deflect Probe deflection scheme, it was discovered that the knowledge and control uncertainties did not significantly affect the critical mission parameters. Therefore, to simplify the Mode 2/Shared Deflection analysis, it was assumed that the knowledge and control uncertainties were zero so that the spacecraft correction, Δv, could be precomputed and simply read in. At probe deflection, the probe is commanded to be aligned in the direction of both the Δv and zero angle of attack orientation. Because of the in-plane and out-of-plane pointing errors, the correct direction is not achieved. The incorrect orientation is then used for both the Δv addition and the probe longitudinal axis. Following the probe deflection, the spacecraft correction is implemented with the execution error model described in subsection A2. The resulting sample deviations are then collected and analyzed to determine the mean and standard deviations.

For Mode 3/Deflect Spacecraft deflection analysis, the knowledge and control uncertainties are again considered. The probe is oriented at release using the input orientation pointing error, δ, and keeps that attitude throughout the mission. The estimated state of the spacecraft, X_{est}, is used to compute the deflection, Δv. Spacecraft execution errors are then sampled to determine the error, $\delta\Delta v$. The erroneous velocity increment is then added to the spacecraft and the spacecraft is then propagated to the selected time points. The critical mission parameter deviations are then recorded and analyzed to determine the important statistical data.

C. REFERENCE

1. R. H. Batten: *Astronautical Guidance*, McGraw-Hill Book Company, New York, N.Y., 1964

C-2

APPENDIX E

ENTRY SCIENCE COMPUTER TAB PRINTOUTS FOR MISSIONS 1A and 7 (PEPSIS PROGRAM)

K. W. Ledbetter

March 22, 1972

P E P S I S

PLANETARY ENTRY PROGRAM FOR SCIENCE INSTRUMENT SIMULATION

MISSION 1A

```
P$INPT
 TITLE=46H TURBOPAUSE DESIGN MISSION 1A, RUN 8  (ACTUAL)    ,
 NCASE=0,
 MODE=1,    NPL=5,    IN=5,     NSTAGE=8,
 RA=5978154.854,-400u9957.162,319766.401,
 VL=-4.74785C757,7.024344294,-0.2895557823,
 ID=1980,11,8,2,32,48,      TI=0,
 RNTRY=72550.,   RTARG=71750.,
 EXPT(1)=10HLANG PROBE,10HMASS SPECT,10H    IRPA  ,10H    NRPA  ,
        10HOPT SPECTR,
 RX(1)=121550.,81550.,73550.,7315C.,73000.,72350.,71850.,
 RX(8)=71750.,71630.,
 DR=10000.,1000.,200.,100.,10u.,1u0.,20.,20.,
 DTI(1,2)=     1,    1,    C,    0,    3.0,
 DTI(1,3)=     1,    C,    0,    C,    3.0,
 DTI(1,4)=     1,    C,    0.5,  1,    3.0,
 DTI(1,5)=     0.5,  0,    0.5,  0,    3.0,
 DTI(1,6)=     0.5,  0,    0.5,  0.5,  3.0,
 DTI(1,7)=     0.5,  0.4,  0.5,  0.5,  3.0,
 DTI(1,8)=     1,    0.4,  0,0,0,
 BPS(1,1)= 32.,192.,112.,194.,432.,
 BPS(1,2)= 32.,192.,112.,194.,432.,
 3PS(1,3)= 32.,192.,112.,194.,432.,
 BPS(1,4)= 32.,192.,112.,194.,432.,
 BPS(1,5)= 32.,192.,112.,194.,432.,
 9PS(1,6)= 32.,192.,112.,194.,432.,
 BPS(1,7)= 32.,192.,112.,194.,432.,
 BPS(1,8)= 32.,192.,112.,194.,432.,
 $
```

TURBOPAUSE DESIGN MISSION 1A, RUN 8 (ACTUAL)

INSTANTANEOUS PARAMETERS AT 1980 11 8 2 52 48 J.D.= 2444551.620000

RADIUS=16000000.000125 VELOCITY= 8.48311
INERTIAL GAMMA=-67.3196 SEPARATION ANGLE= 0.

ENTRY TRAJECTORY ELEMENTS

SEMIMAJOR AXIS=-2.71779094E+06 ECCENTRICITY= 1.02260
PERIAPSIS RADIUS= 61410.3127 VHE= 6.92800
ANGULAR MOMENTUM= 3.96713270E+06 SEMILATUSRECTUM= 1.24208223E+05
ECLIPTIC INCLINATION= 3.25229 EQUATORIAL INCLINATION= 5.40258

ATMOSPHERIC ENTRY CONDITIONS

RADIUS= 72550.000000 INERTIAL VELOCITY= 59.49452
INERTIAL GAMMA= 23.2053 RELATIVE VELOCITY= 47.98702
ENTRY EQUATORIAL LATITUDE= -5.3918
J.D. AT ENTRY= 2444562.503281

VEHICLE ORIENTATION FOR ZERO ANGLE OF ATTACK
-9.95936318E-01 -8.70469279E-02 2.31015817E-02

PLANET-SUN VECTOR
9.96970164E-01 -7.45993197E-02 -2.20325485E-02

```
 BEGIN PHASE  1        REQUIRED BIT RATE=     0.     BITS/SECOND
-------------------------------------------------------------------------------------------------------------------
ALTITUDE  50000.0 KM   TIME    0.      HOURS       TIME     .4604 HOURS        TIME     0.      HOURS  VINERTIAL 46.1686 KM/SEC
  RADIUS 121550.0 KM   FROM    0.      MIN          TO    27.623 MIN          IN      0.      MIN    VRELATIVE 34.4969 KM/SEC
                       RX(1)   0.      SEC         TARG 1657.400 SEC        PHASE   0.      SEC    VRADIAL   32.6536 KM/SEC

GAMMI  45.0138 DEG     DNRNG   0.      DEG         SZA  27.1165 DEG         ALPHA    .9636 DEG
GAMMR  71.1852 DEG     TRUAN 271.2254  DEG         SLA 170.7278 DEG         VEH LAT  -3.7529 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT          0.          0.           0.           0.          0.          0.          0.          0.
NO MEAS TOTAL           0.          0.           0.           0.          0.          0.          0.          0.
NO MEAS PHASE           0.          0.           0.           0.          0.          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)        H1   0.       H2   0.        HE   0.
                (IONS)            H1   0.       H2   0.        H3   0.        HE   0.        HEH   0.
-------------------------------------------------------------------------------------------------------------------
ALTITUDE  40000.0 KM   TIME     .0853 HOURS       TIME     .3751 HOURS        TIME     .0853 HOURS  VINERTIAL 48.1496 KM/SEC
  RADIUS 111550.0 KM   FROM    5.115  MIN          TO    22.508 MIN          IN      5.115  MIN    VRELATIVE 36.1133 KM/SEC
                       RX(1)  306.926  SEC         TARG 1350.474 SEC        PHASE  306.926  SEC    VRADIAL   32.4593 KM/SEC

GAMMI  42.3870 DEG     DNRNG   5.1457  DEG         SZA  32.2616 DEG         ALPHA   2.9998 DEG
GAMMR  64.0033 DEG     TRUAN 276.3711  DEG         SLA 170.7278 DEG         VEH LAT  -4.0408 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT          0.          0.           0.           0.          0.          0.          0.          0.
NO MEAS TOTAL           0.          0.           0.           0.          0.          0.          0.          0.
NO MEAS PHASE           0.          0.           0.           0.          0.          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)        H1   0.       H2   0.        HE   0.
                (IONS)            H1   0.       H2   0.        H3   0.        HE   0.        HEH   0.
-------------------------------------------------------------------------------------------------------------------
ALTITUDE  30000.0 KM   TIME     .1715 HOURS       TIME     .2889 HOURS        TIME     .1715 HOURS  VINERTIAL 50.4192 KM/SEC
  RADIUS 101550.0 KM   FROM   10.290  MIN          TO    17.333 MIN          IN     10.290  MIN    VRELATIVE 38.2381 KM/SEC
                       RX(1)  617.412  SEC         TARG 1039.988 SEC        PHASE  617.412  SEC    VRADIAL   31.8741 KM/SEC

GAMMI  39.2113 DEG     DNRNG  11.3775  DEG         SZA  38.4929 DEG         ALPHA   4.2860 DEG
GAMMR  56.4852 DEG     TRUAN 282.6030  DEG         SLA 170.7278 DEG         VEH LAT  -4.4063 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT          0.          0.           0.           0.          0.          0.          0.          0.
NO MEAS TOTAL           0.          0.           0.           0.          0.          0.          0.          0.
NO MEAS PHASE           0.          0.           0.           0.          0.          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)        H1   0.       H2   0.        HE   0.
                (IONS)            H1   0.       H2   0.        H3   0.        HE   0.        HEH   0.
-------------------------------------------------------------------------------------------------------------------
```

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 TURBOPAUSE DESIGN MISSION 1A, RUN 8  (ACTUAL)
PHASE 1  ENTRY ANGLE  23.205 DEG  INERTIAL AT  72550.0 KM RADIUS
-------------------------------------------------------------------------------------------------------------------
ALTITUDE  24000.0 KM   TIME     .2602 HOURS       TIME     .2002 HOURS       TIME     .2602 HOURS  VINERTIAL 53.0535 KM/SEC
  RADIUS  91550.3 KM   FROM   15.61? MIN         TO    12.010 MIN         IN     15.613 MIN     VRELATIVL 46.9172 KM/SEC
                      RX(1)  936.778 SEC        TARG  720.622 SEC        PHASE  936.778 SEC     VRADIAL   36.6093 KM/SEC

GAMMI  35.2354 DEG     DNRNG  19.1911 DEG       SZA  46.3060 DEG         ALPHA    4.5333 DEG
GAMMR  48.4243 DEG     TRUAN 291.4166 DEG       SLA 173.7278 DEG         VEH LAT  -4.7906 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT           0.          0.          0.           0.          0.          0.          0.          0.
NO MEAS TOTAL            0.          0.          0.           0.          0.          0.          0.          0.
NO MEAS PHASE            0.          0.          0.           0.          0.          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)       H1   0.        H2   0.        HE   0.
                (IONS)           H1   0.        H2   0.        H3   0.        HE   0.        HEM   0.
-------------------------------------------------------------------------------------------------------------------
 BEGIN PHASE  2        REQUIRED BIT RATE=  144.0000 BITS/SECOND
-------------------------------------------------------------------------------------------------------------------
ALTITUDE  10000.0 KM   TIME     .3545 HOURS       TIME     .1059 HOURS       TIME     0.        HOURS  VINERTIAL 56.1614 KM/SEC
  RADIUS  81550.3 KM   FROM   21.269 MIN         TO     6.354 MIN         IN       0.        MIN    VRELATIVL 44.2734 KM/SEC
                      RX(1) 1276.153 SEC        TARG  381.246 SEC        PHASE    0.        SEC    VRADIAL   28.0644 KM/SEC

GAMMI  29.3838 DEG     DNRNG  29.5407 DEG       SZA  56.6553 DEG         ALPHA    3.2705 DEG
GAMMR  39.3376 DEG     TRUAN 300.7661 DEG       SLA 173.7278 DEG         VEH LAT  -5.1617 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT           0.          0.          0.           0.         84.193       0.          0.          0.
NO MEAS TOTAL            0.          0.          0.           0.          0.          0.          0.          0.
NO MEAS PHASE            0.          0.          0.           0.          0.          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)       H1   0.        H2   0.        HE   0.
                (IONS)           H1   0.        H2   0.        H3   0.        HE   0.        HEM   0.
-------------------------------------------------------------------------------------------------------------------
ALTITUDE   9000.0 KM   TIME     .3644 HOURS       TIME     .0959 HOURS       TIME     .0100 HOURS  VINERTIAL 56.5039 KM/SEC
  RADIUS  80550.3 KM   FROM   21.867 MIN         TO     5.756 MIN         IN       .598 MIN     VRELATIVE 44.6510 KM/SEC
                      RX(1) 1312.219 SEC        TARG  345.381 SEC        PHASE   35.865 SEC     VRADIAL   27.6960 KM/SEC

GAMMI  29.3512 DEG     DNRNG  30.7817 DEG       SZA  57.8961 DEG         ALPHA    3.3307 DEG
GAMMR  38.3364 DEG     TRUAN 302.0072 DEG       SLA 173.7278 DEG         VEH LAT  -5.1951 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT           0.          0.          0.           0.         83.068       0.          0.          0.
NO MEAS TOTAL            0.          0.          0.           0.         11.955       0.          0.          0.
NO MEAS PHASE            0.          0.          0.           0.         11.955       0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)       H1   0.        H2   0.        HE   0.
                (IONS)           H1   0.        H2   0.        H3   0.        HE   0.        HEM   0.
-------------------------------------------------------------------------------------------------------------------
```

TURBOPAUSE DESIGN MISSION 1A, RUN 8 (ACTUAL)
PHASE 2 ENTRY ANGLE 23.205 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 8000.0 KM TIME .3746 HOURS TIME .0858 HOURS TIME .0231 HOURS VINERTIAL 56.8527 KM/SEC
RADIUS 79550.0 KM FROM 22.473 MIN TO 5.150 MIN IN 1.234 MIN VRELATIVE 45.0368 KM/SEC
RX(1) 1349.383 SEC TARG 309.017 SEC PHASE 72.230 SEC VRADIAL 27.2993 KM/SEC

GAMMI 28.6968 DEG DNRNG 32.0717 DEG SZA 59.1863 DEG ALPHA 2.7651 DEG
GAMMR 37.3119 DEG TRUAN 303.2971 DEG SLA 170.7278 DEG VEH LAT -5.2272 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	0.	0.	0.	81.858	0.	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	24.077	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	24.077	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 0. H2 0. HE 0.
(IONS) H1 0. H2 0. H3 0. HE 0. HEM 0.

ALTITUDE 7900.0 KM TIME .3848 HOURS TIME .0756 HOURS TIME .0303 HOURS VINERTIAL 57.2083 KM/SEC
RADIUS 79550.0 KM FROM 23.088 MIN TO 4.535 MIN IN 1.819 MIN VRELATIVE 45.4312 KM/SEC
RX(1) 1385.302 SEC TARG 272.100 SEC PHASE 109.147 SEC VRADIAL 26.8715 KM/SEC

GAMMI 28.3157 DEG DNRNG 33.4147 DEG SZA 60.5289 DEG ALPHA 2.4722 DEG
GAMMR 36.2620 DEG TRUAN 304.6431 DEG SLA 170.7278 DEG VEH LAT -5.2578 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	0.	0.	0.	80.615	0.	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	36.382	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	36.382	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 0. H2 0. HE 0.
(IONS) H1 0. H2 0. H3 0. HE 0. HEM 0.

ALTITUDE 6000.0 KM TIME .3952 HOURS TIME .0652 HOURS TIME .0407 HOURS VINERTIAL 57.5707 KM/SEC
RADIUS 77550.0 KM FROM 23.714 MIN TO 3.909 MIN IN 2.445 MIN VRELATIVE 45.8342 KM/SEC
RX(1) 1422.834 SEC TARG 234.566 SEC PHASE 146.680 SEC VRADIAL 26.4097 KM/SEC

GAMMI 27.3355 DEG DNRNG 34.8152 DEG SZA 61.9294 DEG ALPHA 2.1497 DEG
GAMMR 35.1638 DEG TRUAN 306.0407 DEG SLA 170.7278 DEG VEH LAT -5.2865 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	0.	0.	0.	79.229	0.	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	48.893	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	48.893	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 0. H2 0. HE 0.
(IONS) H1 0. H2 0. H3 0. HE 0. HEM 0.

TURBOPAUSE DESIGN MISSION 14, RUN 8 (ACTUAL)
PHASE 2 ENTRY ANGLE -28.205 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 5000.0 KM TIME .4054 HOURS TIME .0545 HOURS TIME .0514 HOURS VINERTIAL 27.9463 KM/SEC
RADIUS 76550.0 KM FROM 24.351 MIN TO 3.272 MIN IN 3.082 MIN VRELATIVE 26.2462 KM/SEC
PK(1) 1461.056 SEC TARG 196.344 SEC PHASE 184.803 SEC VRADIAL 25.9103 KM/SEC

GAMMI 25.5635 DEG DNRNG 36.2738 DEG SZA 63.3929 DEG ALPHA 1.7355 DEG
GAMMR 34.0746 DEG TRUAN 307.5042 DEG SLA 170.7278 DEG VEH LAT -5.3134 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	0.	0.	0.	77.731	0.	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	61.634	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	61.634	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.913 H2 -86.859 H3 -26.194 HE -50.499 HEH -21.521

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.38766E-64		9.01571E-15		4.94277E-71		3.49629E-32		8.12831E-41		3.46737-114
3.75837E-33		1.33330-140		4.73151E-20		1.67343E-38		9.01571E-15		1.77628E-59	

ALTITUDE 4500.0 KM TIME .4167 HOURS TIME .0437 HOURS TIME .0622 HOURS VINERTIAL 28.3172 KM/SEC
RADIUS 75550.0 KM FROM 25.001 MIN TO 2.622 MIN IN 3.732 MIN VRELATIVE 26.6673 KM/SEC
PK(1) 1503.054 SEC TARG 157.346 SEC PHASE 223.911 SEC VRADIAL 25.3691 KM/SEC

GAMMI 25.7865 DEG DNRNG 37.8115 DEG SZA 64.9256 DEG ALPHA 1.4168 DEG
GAMMR 32.9304 DEG TRUAN 309.0370 DEG SLA 170.7278 DEG VEH LAT -5.3376 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	0.	0.	0.	76.107	0.	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	74.634	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	74.634	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.913 H2 -86.859 H3 -26.154 HE -50.499 HEH -21.521

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.18955E-48		1.49624E-10		1.47919E-54		5.29185E-72		2.23872E-32		8.72964E-90
2.98533E-22		3.16228-109		4.73151E-15		6.66284E-30		1.49624E-10		1.41254E-46	

ALTITUDE 3300.0 KM TIME .4278 HOURS TIME .0326 HOURS TIME .0733 HOURS VINERTIAL 28.7317 KM/SEC
RADIUS 74550.0 KM FROM 25.665 MIN TO 1.958 MIN IN 4.396 MIN VRELATIVE 27.3974 KM/SEC
PK(1) 1539.929 SEC TARG 117.470 SEC PHASE 253.776 SEC VRADIAL 24.7814 KM/SEC

GAMMI 24.9709 DEG DNRNG 39.4209 DEG SZA 66.5349 DEG ALPHA .9806 DEG
GAMMR 31.7477 DEG TRUAN 310.6463 DEG SLA 170.7278 DEG VEH LAT -5.3592 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	0.	0.	0.	74.344	0.	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	87.925	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	87.925	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.913 H2 -86.859 H3 -26.194 HE -50.499 HEH -21.521

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	7.49894E-33		2.48313E-06		7.14447E-39		8.30954E-52		6.16595E-24		2.18776E-65
2.37137E-14		1.00000E-77		4.73151E-10		2.65221E-21		2.48313E-06		1.12202E-53	

BEGIN PHASE 3 REQUIRED BIT RATE= 144.0000 BITS/SECOND

```
 TURBOPAUSE DESIGN MISSION 1A, RUN 9  (ACTUAL)
PHASE 3  ENTRY ANGLE  23.205 DEG  INERTIAL AT  72550.0 KM RADIUS

-------------------------------------------------------------------------------------------------------------------------------
ALTITUDE   2300.0 KM   TIME     .4391 HOURS        TIME     .0213 HOURS        TIME     0.      HOURS  VINERTIAL 59.0941 KM/SEC
  RADIUS  73550.0 KM   FROM    26.347 MIN          TO      1.277 MIN          IN       0.      MIN    VRELATIVE 47.5373 KM/SEC
                      RX(1) 1581.885 SEC          TARG   76.595 SEC          PHASE    0.      SEC    VRADIAL   24.1414 KM/SEC

GAMMI  24.1123 DEG     DNRNG  41.1154 DEG        SZA  68.2294 DEG          ALPHA    .5131 DEG
GAMMR  30.5232 DEG     TRUAN 312.3409 DEG        SLA 170.7278 DEG          VEH LAT  -5.3769 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT           0.          0.           0.          0.         72.424          0.          0.          0.
NO MEAS TOTAL            0.          0.           0.          0.        101.376          0.          0.          0.
NO MEAS PHASE            0.          0.           0.          0.          0.             0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)        M1 -54.974     M2 -27.487     ME -13.787
                (IONS)            M1-102.913     M2 -86.859     M3 -26.194     ME -50.499     MEH -21.521
   N(M1)       N(M2)      N(ME)      N(M1+)      N(M2+)      N(M3+)      N(ME+)      N(MEH+)     N(E-)      QE(M1)     QE(M2)     QE(ME)
          4.73151E-17          4.12099E-02          2.71624E-21          1.21229E-31          1.69824E-15          5.49541E-41
 1.88365E-36          3.16228E-46          4.73151E-05          1.05586E-12          4.12099E-02          8.91251E-21
-------------------------------------------------------------------------------------------------------------------------------
ALTITUDE   1800.0 KM   TIME     .4414 HOURS        TIME     .0190 HOURS        TIME     .0023 HOURS  VINERTIAL 59.1735 KM/SEC
  RADIUS  73350.0 KM   FROM    26.485 MIN          TO      1.138 MIN          IN       .138 MIN     VRELATIVE 47.6264 KM/SEC
                      RX(1) 1589.112 SEC          TARG   68.287 SEC          PHASE    8.308 SEC    VRADIAL   24.0066 KM/SEC

GAMMI  23.9349 DEG     DNRNG  41.4655 DEG        SZA  68.5794 DEG          ALPHA    .4143 DEG
GAMMR  30.2690 DEG     TRUAN 312.6939 DEG        SLA 170.7278 DEG          VEH LAT  -5.3831 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT           0.          0.           0.          0.         72.020          0.          0.          0.
NO MEAS TOTAL            0.          0.           0.          0.        134.145          0.          0.          0.
NO MEAS PHASE            0.          0.           0.          0.          2.769          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)        M1 -54.974     M2 -27.487     ME -13.787
                (IONS)            M1-102.911     M2 -86.859     M3 -26.194     ME -50.499     MEH -21.521
   N(M1)       N(M2)      N(ME)      N(M1+)      N(M2+)      N(M3+)      N(ME+)      N(MEH+)     N(E-)      QE(M1)     QE(M2)     QE(ME)
          6.83912E-14          2.87746E-01          5.62291E-18          1.31704E-27          8.27942E-14          4.16869E-36
 7.16143E-05          6.33957E-01          4.73151E-04          5.54124E-11          2.87746E-01          3.38044E-18
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 BEGIN PHASE  4         REQUIRED BIT RATE=  369.0000 BITS/SECOND
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ALTITUDE   1600.0 KM   TIME     .4437 HOURS        TIME     .0166 HOURS        TIME     0.      HOURS  VINERTIAL 59.2532 KM/SEC
  RADIUS  73150.0 KM   FROM    26.624 MIN          TO       .999 MIN          IN       0.      MIN    VRELATIVE 47.7166 KM/SEC
                      RX(1) 1597.467 SEC          TARG   59.933 SEC          PHASE    0.      SEC    VRADIAL   24.0693 KM/SEC

GAMMI  23.7556 DEG     DNRNG  41.8194 DEG        SZA  68.9333 DEG          ALPHA    .3136 DEG
GAMMR  30.0157 DEG     TRUAN 313.0468 DEG        SLA 170.7278 DEG          VEH LAT  -5.3833 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT           0.          0.          11.935       0.         71.618          0.          0.          0.
NO MEAS TOTAL            0.          0.           0.          0.        106.923          0.          0.          0.
NO MEAS PHASE            0.          0.           0.          0.          0.             0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)        M1 -54.974     M2 -27.487     ME -13.787
                (IONS)            M1-102.896     M2 -86.859     M3 -26.195     ME -50.499     MEH -21.522
   N(M1)       N(M2)      N(ME)      N(M1+)      N(M2+)      N(M3+)      N(ME+)      N(MEH+)     N(E-)      QE(M1)     QE(M2)     QE(ME)
          9.88553E-11          2.00941E+00          1.16386E-14          1.47067E-23          4.03545E-12          3.16228E-31
 2.72278E-03          1.25493E-33          4.73151E-03          2.93839E-39          2.00941E+00          1.28825E-15
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TURBOPAUSE DESIGN MISSION 1A, RUN 8 (ACTUAL)
PHASE 4 ENTRY ANGLE 23.205 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 1500.0 KM TIME .4449 HOURS TIME .0155 HOURS TIME .0012 HOURS VINERTIAL 59.2933 KM/SEC
RADIUS 73350.0 KM FROM 26.694 MIN TO .929 MIN IN .070 MIN VRELATIVE 47.7609 KM/SEC
RX(1) 16001.663 SEC TARG 55.737 SEC PHASE 4.196 SEC VRADIAL 23.7998 KM/SEC

GAMMI 23.6652 DEG DNRNG 41.9979 DEG SZA 69.1118 DEG ALPHA .2626 DEG
GAMMR 29.8883 DEG TRUAN 313.2233 DEG SLA 170.7278 DEG VEH LAT -5.3844 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	0.	11.900	0.	71.399	0.	0.	0.
NO MEAS TOTAL	0.	0.	8.391	0.	108.321	0.	0.	0.
NO MEAS PHASE	0.	0.	8.391	0.	1.399	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.865 H2 -86.859 H3 -26.197 HE -50.499 HEH -21.523

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	3.75837E-09		5.31121E+03		5.29390E-13		1.49076E-21		2.81838E-11		8.70964E-29
1.67880E-02		1.77828E-30		1.49623E-02		2.10672E-08		5.31121E+00		2.51169E-14	

BEGIN PHASE 5 REQUIRED BIT RATE= 432.0000 BITS/SECOND

ALTITUDE 1450.0 KM TIME .4455 HOURS TIME .0149 HOURS TIME .0 HOURS VINERTIAL 59.3133 KM/SEC
RADIUS 73000.0 KM FROM 26.729 MIN TO .894 MIN IN 0. MIN VRELATIVE 47.7834 KM/SEC
RX(1) 16023.765 SEC TARG 53.635 SEC PHASE 0. SEC VRADIAL 23.7648 KM/SEC

GAMMI 23.6198 DEG DNRNG 42.0875 DEG SZA 69.2014 DEG ALPHA .2369 DEG
GAMMR 29.8244 DEG TRUAN 313.3129 DEG SLA 170.7278 DEG VEH LAT -5.3851 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.882	0.	11.882	0.	71.294	0.	0.	0.
NO MEAS TOTAL	0.	0.	12.593	0.	109.021	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.833 H2 -86.859 H3 -26.199 HE -50.499 HEH -21.525

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	2.31739E-08		4.63621E+03		3.56981E-12		1.52154E-20		7.44732E-11		1.44544E-27
4.16869E-02		6.69344E-29		2.66372E-02		5.67032E-08		8.63621E+00		1.10917E-13	

ALTITUDE 1350.0 KM TIME .4467 HOURS TIME .0137 HOURS TIME .0012 HOURS VINERTIAL 59.3534 KM/SEC
RADIUS 72900.0 KM FROM 26.803 MIN TO .824 MIN IN .070 MIN VRELATIVE 47.8285 KM/SEC
RX(1) 16047.979 SEC TARG 49.420 SEC PHASE 4.214 SEC VRADIAL 23.6943 KM/SEC

GAMMI 23.5286 DEG DNRNG 42.2675 DEG SZA 69.3814 DEG ALPHA .1851 DEG
GAMMR 29.6962 DEG TRUAN 313.4929 DEG SLA 170.7278 DEG VEH LAT -5.3864 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.847	0.	11.847	0.	71.083	0.	0.	0.
NO MEAS TOTAL	8.428	0.	21.021	0.	110.426	0.	0.	0.
NO MEAS PHASE	8.428	0.	8.428	0.	1.405	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.699 H2 -86.861 H3 -26.259 HE -50.499 HEH -21.531

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	8.81049E-07		2.28508E+01		1.62234E-10		1.58382E-18		5.19996E-10		3.98107E-25
2.57043E-01		9.44061E-26		8.41381E-02		4.13778E-07		2.28508E+01		2.16272E-12	

TURBOPAUSE DESIGN MISSION 1A, RUN 5 (ACTUAL)
PHASE 5 ENTRY ANGLE 23.295 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 1250.0 KM TIME .4478 HOURS TIME .0126 HOURS TIME .0023 HOURS VINERTIAL 59.3936 KM/SEC
RADIUS 72800.0 KM FROM 26.873 MIN TO .753 MIN IN .141 MIN VRELATIVE 47.8737 KM/SEC
RX(1) 1612.206 SEC TARG 45.194 SEC PHASE 8.441 SEC VRADIAL 23.6231 KM/SEC

GAMMI 23.4369 DEG DNRNG 42.4485 DEG SZA 69.5624 DEG ALPHA .1328 DEG
GAMMR 29.5674 DEG TRUAN 313.6739 DEG SLA 170.7278 DEG VEH LAT -5.3877 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.812	0.	11.812	0.	70.869	0.	0.	0.
NO MEAS TOTAL	16.882	0.	29.475	0.	111.835	0.	0.	0.
NO MEAS PHASE	16.882	0.	16.882	0.	2.814	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.293 H2 -86.873 H3 -26.236 HE -50.499 HEH -21.548

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
1.58489E+00	3.34965E-05	1.33352E-22	5.06048E+01	2.66144E-01	7.35219E-09	2.97582E-06	1.64475E-16	6.03048E+01	3.53078E-09	4.21697E-11	1.09648E-22

ALTITUDE 1150.0 KM TIME .4490 HOURS TIME .0114 HOURS TIME .0035 HOURS VINERTIAL 59.4339 KM/SEC
RADIUS 72700.0 KM FROM 26.941 MIN TO .683 MIN IN .211 MIN VRELATIVE 47.9189 KM/SEC
RX(1) 1616.446 SEC TARG 40.954 SEC PHASE 12.686 SEC VRADIAL 23.5513 KM/SEC

GAMMI 23.3446 DEG DNRNG 42.6306 DEG SZA 69.7445 DEG ALPHA .0801 DEG
GAMMR 29.4381 DEG TRUAN 313.8560 DEG SLA 170.7278 DEG VEH LAT -5.3890 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.776	0.	11.776	0.	70.654	0.	0.	0.
NO MEAS TOTAL	25.361	0.	37.954	0.	113.248	0.	0.	0.
NO MEAS PHASE	25.361	0.	25.361	0.	4.227	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-101.235 H2 -86.948 H3 -26.313 HE -50.499 HEH -21.596

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
9.77237E+00	1.27350E-03	1.98365E-19	1.61781E+02	8.40847E-01	3.30949E-07	2.15579E-05	1.69700E-14	1.61781E+02	2.53513E-08	8.22243E-10	3.01995E-20

ALTITUDE 1050.0 KM TIME .4502 HOURS TIME .0102 HOURS TIME .0047 HOURS VINERTIAL 59.4743 KM/SEC
RADIUS 72600.0 KM FROM 27.012 MIN TO .612 MIN IN .282 MIN VRELATIVE 47.9643 KM/SEC
RX(1) 1620.698 SEC TARG 36.702 SEC PHASE 16.933 SEC VRADIAL 23.4789 KM/SEC

GAMMI 23.2519 DEG DNRNG 42.8137 DEG SZA 69.9276 DEG ALPHA .0268 DEG
GAMMR 29.3082 DEG TRUAN 314.0392 DEG SLA 170.7278 DEG VEH LAT -5.3902 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.739	0.	11.739	0.	70.437	0.	0.	0.
NO MEAS TOTAL	33.866	0.	46.459	0.	114.666	0.	0.	0.
NO MEAS PHASE	33.866	0.	33.866	0.	5.644	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1 -98.630 H2 -87.412 H3 -26.538 HE -50.499 HEH -21.718

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
6.02560E+01	4.84172E-02	2.66373E-16	4.39294E+02	2.65308E+00	1.46041E-05	1.56173E-04	1.72128E-12	4.39294E+02	1.77011E-07	1.60325E-08	8.31764E-18

TURBOPAUSE DESIGN MISSION 1A, RUN 8 (ACTUAL)
PHASE 5 ENTRY ANGLE -28.205 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 950.0 KM TIME .4514 HOURS TIME .0090 HOURS TIME .0059 HOURS VINERTIAL 59.5148 KM/SEC
RADIUS 72500.0 KM FROM 27.083 MIN TO .541 MIN IN .353 MIN VRELATIVE 48.0098 KM/SEC
RX(1) 1624.964 SEC TARG 32.436 SEC PHASE 21.199 SEC VRADIAL 23.4058 KM/SEC

GAMMI 23.1585 DEG DNRNG 42.9979 DEG SZA 70.1118 DEG ALPHA .0269 DEG
GAMMR 29.1778 DEG TRUAN 314.2234 DEG SLA 170.7278 DEG VEH LAT -5.3913 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.703	0.	11.703	0.	70.217	0.	0.	0.
NO MEAS TOTAL	42.398	0.	54.991	0.	116.088	0.	0.	0.
NO MEAS PHASE	42.398	0.	42.398	0.	7.066	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1 -93.546 H2 -90.313 H3 -27.201 HE -50.499 HEH -21.981

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.84077E+00		1.24137E+03		6.08753E-04		1.67767E-10		1.23595E-06		2.29087E-15
3.71535E+02		3.75837E-13		8.21056E+00		1.13138E-03		1.24137E+03		3.12608E-07	

ALTITUDE 850.0 KM TIME .4526 HOURS TIME .0078 HOURS TIME .0071 HOURS VINERTIAL 59.5553 KM/SEC
RADIUS 72400.0 KM FROM 27.154 MIN TO .469 MIN IN .425 MIN VRELATIVE 48.0553 KM/SEC
RX(1) 1629.243 SEC TARG 28.157 SEC PHASE 25.478 SEC VRADIAL 23.3320 KM/SEC

GAMMI 23.0647 DEG DNRNG 43.1832 DEG SZA 70.2971 DEG ALPHA .0812 DEG
GAMMR 29.0467 DEG TRUAN 314.4087 DEG SLA 170.7278 DEG VEH LAT -5.3924 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.666	0.	11.666	0.	69.956	0.	0.	0.
NO MEAS TOTAL	50.956	0.	63.549	0.	117.514	0.	0.	0.
NO MEAS PHASE	50.956	0.	50.956	0.	8.493	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1 -89.214 H2-109.885 H3 -29.178 HE -50.499 HEH -22.235

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	6.99642E+01		3.73060E+03		2.16498E-02		1.53754E-08		8.62979E-06		6.30957E-13
2.29087E+03		5.31884E-10		2.30816E+01		8.19610E-03		3.73062E+03		6.09537E-06	

BEGIN PHASE 6 REQUIRED BIT RATE= 820.0000 BITS/SECOND

ALTITUDE 800.0 KM TIME .4532 HOURS TIME .0072 HOURS TIME 0. HOURS VINERTIAL 59.5756 KM/SEC
RADIUS 72350.0 KM FROM 27.190 MIN TO .434 MIN IN 0. MIN VRELATIVE 48.0782 KM/SEC
RX(1) 1631.389 SEC TARG 26.012 SEC PHASE 0. SEC VRADIAL 23.2948 KM/SEC

GAMMI 23.0175 DEG DNRNG 43.2763 DEG SZA 70.3902 DEG ALPHA .1086 DEG
GAMMR 28.9810 DEG TRUAN 314.5017 DEG SLA 170.7278 DEG VEH LAT -5.3930 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.647	0.	11.647	11.647	69.884	0.	0.	0.
NO MEAS TOTAL	55.242	0.	67.835	0.	118.228	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1 -91.490 H2-153.645 H3 -31.290 HE -50.499 HEH -22.098

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	4.31519E+02		6.50512E+03		1.13776E-01		1.46335E-07		2.28034E-05		1.04713E-11
5.68853E+03		1.99526E-08		3.43040E+01		2.20601E-02		6.50524E+03		2.09153E-05	

TURBOPAUSE DESIGN MISSION 1A, RUN 5 (ACTUAL)
PHASE 6 ENTRY ANGLE 23.205 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 700.0 KM TIME .4544 HOURS TIME .0060 HOURS TIME .0012 HOURS VINERTIAL 59.6163 KM/SEC
RADIUS 72250.0 KM FROM 27.261 MIN TO .362 MIN IN .072 MIN VRELATIVE 48.1239 KM/SEC
RX(1) 1635.688 SEC TARG 21.712 SEC PHASE 4.300 SEC VRADIAL 23.2200 KM/SEC

GAMMI 22.9228 DEG DNRNG 43.4633 DEG SZA 70.5771 DEG ALPHA .1636 DEG
GAMMR 28.8491 DEG TRUAN 314.6887 DEG SLA 170.7278 DEG VEH LAT -5.3940 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.610	0.	11.610	11.610	69.660	0.	0.	0.
NO MEAS TOTAL	63.841	0.	76.434	8.599	119.662	0.	0.	0.
NO MEAS PHASE	8.599	0.	8.599	8.599	1.433	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-109.859 H2 815.069 H3 -38.389 HE -50.499 HEH -21.241

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.64059E+04		1.77869E+04		2.06654E+00		1.47393E-05		1.59221E-04		2.88403E-09
3.50752E+04		2.81838E-05		4.48153E+01		1.59811E-01		1.77890E+04		5.24807E-04	

ALTITUDE 600.0 KM TIME .4556 HOURS TIME .0048 HOURS TIME .0024 HOURS VINERTIAL 59.6570 KM/SEC
RADIUS 72150.0 KM FROM 27.333 MIN TO .290 MIN IN .144 MIN VRELATIVE 48.1697 KM/SEC
RX(1) 1640.001 SEC TARG 17.399 SEC PHASE 8.613 SEC VRADIAL 23.1445 KM/SEC

GAMMI 22.8275 DEG DNRNG 43.6514 DEG SZA 70.7652 DEG ALPHA .2192 DEG
GAMMR 28.7166 DEG TRUAN 314.8768 DEG SLA 170.7278 DEG VEH LAT -5.3953 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.572	0.	11.572	11.572	69.433	0.	0.	0.
NO MEAS TOTAL	72.469	0.	85.062	17.227	121.099	0.	0.	0.
NO MEAS PHASE	17.227	0.	17.227	17.227	2.871	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-118.291 H2 181.939 H3 -44.596 HE -50.499 HEH -20.954

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	6.23735E+05		4.21235E+04		2.27053E+01		1.71365E-03		1.11173E-03		7.94328E-07
2.16272E+05		3.34107E-02		3.16442E+01		1.15773E+00		4.21461E+04		1.02329E-02	

ALTITUDE 500.0 KM TIME .4568 HOURS TIME .0036 HOURS TIME .0036 HOURS VINERTIAL 59.6979 KM/SEC
RADIUS 72050.0 KM FROM 27.405 MIN TO .218 MIN IN .216 MIN VRELATIVE 48.2157 KM/SEC
RX(1) 1644.329 SEC TARG 13.071 SEC PHASE 12.941 SEC VRADIAL 23.0682 KM/SEC

GAMMI 22.7317 DEG DNRNG 43.8406 DEG SZA 70.9545 DEG ALPHA .2753 DEG
GAMMR 28.5835 DEG TRUAN 315.1660 DEG SLA 170.7278 DEG VEH LAT -5.3959 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	11.534	0.	11.534	11.534	69.205	0.	0.	0.
NO MEAS TOTAL	81.124	0.	93.717	25.882	122.542	0.	0.	0.
NO MEAS PHASE	25.882	0.	25.882	25.882	4.314	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-113.029 H2 154.505 H3 -47.534 HE -50.499 HEH -21.134

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	2.37137E+07		9.98112E+04		1.97314E+02		1.98966E-01		7.76247E-03		2.18776E-04
1.33352E+06		5.62341E+01		1.68424E+01		8.38701E+00		1.00007E+05		1.99526E-01	

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 TURBOPAUSE DESIGN MISSION 1A, RUN 8  (ACTUAL)
PHASE 6  ENTRY ANGLE  23.235 DEG  INERTIAL AT  72550.0 KM RADIUS

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ALTITUDE    400.0 KM   TIME     .4580 HOURS        TIME     .0024 HOURS        TIME      .0048 HOURS  VINERTIAL 59.7388 KM/SEC
  RADIUS  71950.0 KM   FROM   27.478 MIN          TO       .145 MIN           IN        .288 MIN     VRELATIVE 48.2617 KM/SEC
                       RX(1) 1644.671 SEC         TARG    8.729 SEC          PHASE   17.283 SEC     VRADIAL   22.9313 KM/SEC

GAMMI  22.6352 DEG     DNRNG  44.0310 DEG        SZA  71.1448 DEG          ALPHA     .3323 DEG
GAMMR  28.4497 DEG     TRUAN 315.2564 DEG        SLA 170.7278 DEG          VEH LAT  -5.3967 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA        NRPA     OPT SPECTR
KM/MEASUREMENT          11.496        0.         11.496      11.496      68.974        0.          0.          0.
NO MEAS TOTAL           89.809        0.        102.402      34.567     123.989        0.          0.          0.
NO MEAS PHASE           34.567        0.         34.567      34.567       5.761        0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)       H1 -54.974     H2 -27.487     HE -13.787
                (IONS)           H1-108.378     H2 151.340     H3 -48.840     HE -50.499     HEH -21.323
   N(H1)       N(H2)      N(HE)      N(H1+)     N(H2+)     N(H3+)     N(HE+)     N(HEH+)     N(E-)      QE(H1)     QE(H2)     QE(HE)
          9.01571E+08          2.46832E+05          1.56584E+03          2.20844E+01          5.42001E-02          6.02560E-02
 8.22243E+06          7.94328E+04          8.62665E+00          6.07585E+01          2.43350E+05          3.89045E+00
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 BEGIN PHASE  7         REQUIRED BIT RATE= 1300.0000 BITS/SECOND
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ALTITUDE    300.0 KM   TIME     .4592 HOURS        TIME     .0012 HOURS        TIME      0.      HOURS  VINERTIAL 59.7798 KM/SEC
  RADIUS  71850.0 KM   FROM   27.550 MIN          TO       .073 MIN           IN        0.      MIN    VRELATIVE 48.3075 KM/SEC
                       RX(1) 1657.028 SEC         TARG    4.372 SEC          PHASE     0.      SEC    VRADIAL   22.9136 KM/SEC

GAMMI  22.5382 DEG     DNRNG  44.2226 DEG        SZA  71.3364 DEG          ALPHA     .3392 DEG
GAMMR  28.3154 DEG     TRUAN 315.4480 DEG        SLA 170.7278 DEG          VEH LAT  -5.3976 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA        NRPA     OPT SPECTR
KM/MEASUREMENT          11.457        9.165      11.457      11.457      68.741        0.          0.          0.
NO MEAS TOTAL           98.509        0.        111.101      43.266     125.459        0.          0.          0.
NO MEAS PHASE            0.           0.          0.          0.          0.          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)       H1 -54.974     H2 -27.487     HE -13.787
                (IONS)           H1-104.121     H2  17.274     H3  32.042     HE -50.499     HEH -21.515
   N(H1)       N(H2)      N(HE)      N(H1+)     N(H2+)     N(H3+)     N(HE+)     N(HEH+)     N(E-)      QE(H1)     QE(H2)     QE(HE)
          3.42768E+10          6.14715E+05          4.86315E+02          2.44612E+03          3.78443E-01          1.65959E+01
 5.06991E+07          1.13202E+08          1.46241E-01          4.43157E+02          6.16845E+05          1.00000E+00
-------------------------------------------------------------------------------------------------------------------------------
ALTITUDE    280.3 KM   TIME     .4594 HOURS        TIME     .0010 HOURS        TIME      .0002 HOURS  VINERTIAL 59.7886 KM/SEC
  RADIUS  71930.3 KM   FROM   27.565 MIN          TO       .058 MIN           IN        .015 MIN     VRELATIVE 48.3171 KM/SEC
                       RX(1) 1653.901 SEC         TARG    3.499 SEC          PHASE     .873 SEC     VRADIAL   22.8980 KM/SEC

GAMMI  22.5187 DEG     DNRNG  44.2618 DEG        SZA  71.3748 DEG          ALPHA     .4007 DEG
GAMMR  28.2884 DEG     TRUAN 315.4864 DEG        SLA 170.7278 DEG          VEH LAT  -5.3977 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA        NRPA     OPT SPECTR
KM/MEASUREMENT          11.449        9.159      11.449      11.449      68.694        0.          0.          0.
NO MEAS TOTAL          100.254        2.183     112.847      45.312     125.730        0.          0.          0.
NO MEAS PHASE            1.746        2.183       1.746       1.746        .291        0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)       H1 -54.974     H2 -27.487     HE -13.787
                (IONS)           H1-102.839     H2   4.751     H3   5.441     HE   3.750     HEH   4.168
   N(H1)       N(H2)      N(HE)      N(H1+)     N(H2+)     N(H3+)     N(HE+)     N(HEH+)     N(E-)      QE(H1)     QE(H2)     QE(HE)
          7.09578E+10          7.47123E+05          1.49998E+01          6.09992E+01          5.58213E-01          5.01187E-01
 7.29458E+07          4.78630E+08          3.15875E-03          6.42107E+00          7.47184E+05          6.66827E-02
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 TURBOPAUSE DESIGN MISSION 1A, RUN A  (ACTUAL)
PHASE 7  ENTRY ANGLE  23.205 DEG  INERTIAL AT  72550.0 KM RADIUS

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ALTITUDE    260.0 KM   TIME     .4597 HOURS        TIME     .0007 HOURS        TIME      .0005 HOURS  VINERTIAL 59.7963 KM/SEC
  RADIUS  71910.0 KM   FROM    27.580 MIN          TO       .044 MIN          IN        .029 MIN    VRELATIVE 48.3263 KM/SEC
                      RX(1) 1654.775 SEC          TARG    2.625 SEC          PHASE    1.747 SEC    VRADIAL   22.8823 KM/SEC

GAMMI  22.4992 DEG     DNRNG  44.2995 DEG        SZA  71.4134 DEG          ALPHA     .4122 DEG
GAMMR  23.2615 DEG     TRUAN 315.5249 DEG        SLA 170.7278 DEG          VEH LAT  -5.3979 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT          11.441       9.153      11.441       11.441      68.647          0.           0.           0.
NO MEAS TOTAL          132.001       4.367     114.594       46.759     126.022          0.           0.           0.
NO MEAS PHASE            3.494       4.367       3.494        3.494        .562          0.           0.           0.

SCALE HEIGHTS   (NEUTRALS)        H1 -54.974     H2 -27.487     HE -13.787
                (IONS)            H1-132.917     H2   5.527     H3   6.482     HE   3.750     HEM   4.174
   N(H1)       N(H2)      N(HE)      N(H1+)      N(H2+)      N(H3+)      N(HE+)      N(HEM+)     N(E-)       QE(H1)      QE(H2)      QE(HE)
          1.46893E+11              3.07402E+05              5.38642E-01              5.03617E-01              8.23379E-01              5.01187E-03
 1.04954E+08          2.04174E+09          6.65473E-05          3.13175E-02          9.37403E+05          4.44631E-03
-------------------------------------------------------------------------------------------------------------------------------
ALTITUDE    240.0 KM   TIME     .4599 HOURS        TIME     .0005 HOURS        TIME      .0007 HOURS  VINERTIAL 59.8045 KM/SEC
  RADIUS  71790.0 KM   FROM    27.594 MIN          TO       .029 MIN          IN        .044 MIN    VRELATIVE 48.3356 KM/SEC
                      RX(1) 1655.649 SEC          TARG    1.750 SEC          PHASE    2.621 SEC    VRADIAL   22.8666 KM/SEC

GAMMI  22.4797 DEG     DNRNG  44.3381 DEG        SZA  71.4519 DEG          ALPHA     .4237 DEG
GAMMR  23.2345 DEG     TRUAN 315.5635 DEG        SLA 170.7278 DEG          VEH LAT  -5.3981 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT          11.433       9.147      11.433       11.433      68.600          0.           0.           0.
NO MEAS TOTAL          133.750       6.553     116.343       49.508     126.313          0.           0.           0.
NO MEAS PHASE            5.242       6.553       5.242        5.242        .874          0.           0.           0.

SCALE HEIGHTS   (NEUTRALS)        H1 -54.974     H2 -27.487     HE -13.787
                (IONS)            H1-102.913     H2   5.765     H3   6.812     HE   3.750     HEM   4.256
   N(H1)       N(H2)      N(HE)      N(H1+)      N(H2+)      N(H3+)      N(HE+)      N(HEM+)     N(E-)       QE(H1)      QE(H2)      QE(HE)
          3.04389E+11              1.10205E+06              2.71591E-02              4.28992E-03              1.21451E+00              5.01187E-05
 1.51008E+08          8.70964E+09          1.96847E-06          1.49833E-04          1.13205E+06          2.96483E-04
-------------------------------------------------------------------------------------------------------------------------------
ALTITUDE    220.0 KM   TIME     .4601 HOURS        TIME     .0002 HOURS        TIME      .0010 HOURS  VINERTIAL 59.8127 KM/SEC
  RADIUS  71770.0 KM   FROM    27.609 MIN          TO       .015 MIN          IN        .058 MIN    VRELATIVE 48.3448 KM/SEC
                      RX(1) 1656.524 SEC          TARG     .876 SEC          PHASE    3.496 SEC    VRADIAL   22.8539 KM/SEC

GAMMI  22.4632 DEG     DNRNG  44.3767 DEG        SZA  71.4905 DEG          ALPHA     .4353 DEG
GAMMR  23.2074 DEG     TRUAN 315.6021 DEG        SLA 170.7278 DEG          VEH LAT  -5.3982 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA         NRPA     OPT SPECTR
KM/MEASUREMENT          11.425       9.140      11.425       11.425      68.553          0.           0.           0.
NO MEAS TOTAL          105.500       8.740     118.093       53.254     126.645          0.           0.           0.
NO MEAS PHASE            6.992       8.740       6.992        6.992        1.185          0.           0.           0.

SCALE HEIGHTS   (NEUTRALS)        H1 -54.974     H2 -16.266     HE -13.787
                (IONS)            H1-102.913     H2   5.071     H3   6.876     HE   3.428     HEM   4.730
   N(H1)       N(H2)      N(HE)      N(H1+)      N(H2+)      N(H3+)      N(HE+)      N(HEM+)     N(E-)       QE(H1)      QE(H2)      QE(HE)
          8.83180E+11              1.33844E+05              1.46035E-03              4.63942E-05              1.79143E+00              5.01187E-07
 2.17270E+08          3.71535E+10          4.45010E-08          5.15950E-07          1.33844E+06          1.97697E-05
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 BEGIN PHASE  8         REQUIRED BIT RATE=  480.0000 BITS/SECOND
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TURBOPAUSE DESIGN MISSION 1A, RUN 8 (ACTUAL)
PHASE 9 ENTRY ANGLE 23.205 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 209.0 KM TIME .4604 HOURS TIME 0. HOURS TIME 0. HOURS VINERTIAL 59.8209 KM/SEC
RADIUS 71759.0 KM FROM 27.623 MIN TO 0. MIN IN 0. MIN VRELATIVE 48.3541 KM/SEC
RX(1) 1657.403 SEC TARG 0. SEC PHASE 0. SEC VRADIAL 22.8351 KM/SEC

GAMMI 22.4406 DEG DNRNG 44.4153 DEG SZA 71.5291 DEG ALPHA .4469 DEG
GAMMR 28.1804 DEG TRUAN 315.6437 DEG SLA 170.7278 DEG VEH LAT -5.3983 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	9.134	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	107.250	10.928	119.843	52.008	126.896	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 2.915 H2 5.376 H3 -4.619 HE 3.428 HEH -5.216

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	3.01395E+12	1.62555E+06		8.02798E-05		1.12292E-06		2.64241E+01		5.01187E-09	
3.12608E+08			1.58489E+11		5.64244E-10		1.53872E-09		1.62555E+06		1.31828E-06

ALTITUDE 186.3 KM TIME .4606 HOURS TIME -.0002 HOURS TIME .0002 HOURS VINERTIAL 59.8292 KM/SEC
RADIUS 71730.0 KM FROM 27.638 MIN TO -.015 MIN IN .015 MIN VRELATIVE 48.3633 KM/SEC
RX(1) 1658.276 SEC TARG -.876 SEC PHASE .876 SEC VRADIAL 22.8194 KM/SEC

GAMMI 22.4216 DEG DNRNG 44.4543 DEG SZA 71.5678 DEG ALPHA .4585 DEG
GAMMR 28.1533 DEG TRUAN 315.6794 DEG SLA 170.7278 DEG VEH LAT -5.3985 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	9.124	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	107.250	13.119	119.843	52.008	126.896	0.	0.	0.
NO MEAS PHASE	0.	2.190	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 2.713 H2 5.076 H3 -4.299 HE 3.428 HEH -4.176

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.03276E+13	1.99506E+02		4.34828E-02		5.92141E-04		3.98137E-08		5.01187E-11	
4.49783E+08			6.76383E+11		1.68035E-11		4.41171E-12		1.99553E+02		8.79823E-08

ALTITUDE 160.9 KM TIME .4609 HOURS TIME -.0005 HOURS TIME .0005 HOURS VINERTIAL 59.8374 KM/SEC
RADIUS 71710.0 KM FROM 27.653 MIN TO -.029 MIN IN .029 MIN VRELATIVE 48.3726 KM/SEC
RX(1) 1659.153 SEC TARG -1.753 SEC PHASE 1.753 SEC VRADIAL 22.8036 KM/SEC

GAMMI 22.4014 DEG DNRNG 44.4927 DEG SZA 71.6066 DEG ALPHA .4702 DEG
GAMMR 28.1262 DEG TRUAN 315.7182 DEG SLA 170.7278 DEG VEH LAT -5.3986 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	9.121	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	107.250	15.311	119.843	52.008	126.896	0.	0.	0.
NO MEAS PHASE	0.	4.382	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 2.916 H2 5.075 H3 21.681 HE 3.428 HEH 28.097

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	3.53183E+13	4.68497E-02		7.30572E-01		1.19891E-02		1.58489E-14		5.01187E-13	
6.47143E+08			2.88403E+12		3.26585E-13		1.29005E-14		7.89411E-01		5.86138E-09

TURBOPAUSE DESIGN MISSION 1A, RUN 5 (ACTUAL)
PHASE 6 ENTRY ANGLE 23.255 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 140.3 KM TIME .4611 HOURS TIME -.0007 HOURS TIME .0007 HOURS VINERTIAL 59.8456 KM/SEC
RADIUS 71690.0 KM FROM 27.667 MIN TO -.044 MIN IN .044 MIN VRELATIVE 48.3818 KM/SEC
RX(1) 1660.030 SEC TARG -2.630 SEC PHASE 2.630 SEC VRADIAL 22.7877 KM/SEC

GAMMI 22.3917 DEG DNRNG 44.5315 DEG SZA 71.6454 DEG ALPHA .4818 DEG
GAMMR 28.0991 DEG TRUAN 315.7570 DEG SLA 170.7278 DEG VEH LAT -5.3987 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	9.115	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	107.250	17.504	119.843	52.008	126.896	0.	0.	0.
NO MEAS PHASE	0.	6.576	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 8.017 H2 5.074 H3 14.795 HE 3.428 HEH 17.667

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
1.66781E+14		2.96495E-03		1.92301E-01		3.91982E-33		6.33957E-21		5.01187E-15	
9.31108E+08		1.23027E+13		6.34266E-15		3.77231E-17		1.99166E-01		3.90841E-10	

ALTITUDE 120.0 KM TIME .4614 HOURS TIME -.0010 HOURS TIME .0010 HOURS VINERTIAL 59.8539 KM/SEC
RADIUS 71670.0 KM FROM 27.682 MIN TO -.058 MIN IN .058 MIN VRELATIVE 48.3911 KM/SEC
RX(1) 1660.908 SEC TARG -3.508 SEC PHASE 3.508 SEC VRADIAL 22.7719 KM/SEC

GAMMI 22.3620 DEG DNRNG 44.5704 DEG SZA 71.6842 DEG ALPHA .4935 DEG
GAMMR 28.0719 DEG TRUAN 315.7958 DEG SLA 170.7278 DEG VEH LAT -5.3989 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	9.109	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	107.250	19.699	119.843	52.008	126.896	0.	0.	0.
NO MEAS PHASE	0.	8.771	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 8.999 H2 5.372 H3 14.742 HE 3.428 HEH 17.610

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
4.13348E+14		3.21939E-04		4.96286E-02		1.26123E-03		2.51189E-27		5.01187E-17	
1.33969E+09		5.24937E+13		1.23364E-16		1.10328E-19		5.12118E-02		2.60615E-11	

ALTITUDE 100.3 KM TIME .4616 HOURS TIME -.0012 HOURS TIME .0012 HOURS VINERTIAL 59.8621 KM/SEC
RADIUS 71650.0 KM FROM 27.696 MIN TO -.073 MIN IN .073 MIN VRELATIVE 48.4004 KM/SEC
RX(1) 1661.787 SEC TARG -4.387 SEC PHASE 4.387 SEC VRADIAL 22.7560 KM/SEC

GAMMI 22.3423 DEG DNRNG 44.6093 DEG SZA 71.7231 DEG ALPHA .5152 DEG
GAMMR 28.0447 DEG TRUAN 315.8347 DEG SLA 170.7278 DEG VEH LAT -5.3990 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	OPT SPECTR			
KM/MEASUREMENT	0.	9.102	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	107.250	21.896	119.843	52.008	126.896	0.	0.	0.
NO MEAS PHASE	0.	10.967	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 9.987 H2 5.371 H3 14.711 HE 3.428 HEH 17.567

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
1.41254E+15		3.48263E-05		1.27637E-02		4.04491E-04		1.00000E-33		5.01187E-19	
1.92752E+09		2.23872E+14		2.38494E-18		3.22558E-22		1.32000E-02		1.73780E-12	

P E P S I S

PLANETARY ENTRY PROGRAM FOR SCIENCE INSTRUMENT SIMULATION

MISSION 7

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PSINPT
 TITLE=46H TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)      ,
 NCASE=0,
 MODE=1,    NPL=5,    IN=6,     NSTAGE=8,
 PA=69335.59, 21364.31, -1950.389,
 VL= -46.39219, 38.311445, -0.1877486,
 ID=1979,2,19,          TI=0,
 RNTRY=72550.,  RTARG=71750.,
 EXPT(1)=10HLANG PROBE,10HMASS SPECT,10H    IRPA  ,10H    NPPA  ,
         10H  H2 PHOTM,10H  HE PHOTM,
 RX(1)=121550.,81550.,73550.,73150.,73000.,72350.,71850.,
 RX(8)=71750.,71630.,
 DR=10000.,2500.,200.,100.,100.,100.,20.,20.,
 DTI(1,2)=     0.    0.    0.    0.    3.0, 3.0,
 DTI(1,3)=     0.    0.    0.    0.    3.0, 3.0,
 DTI(1,4)=     0.    0.    0.5,  0.    3.0, 3.0,
 DTI(1,5)=     0.5,  0.    0.5,  0.    3.0, 3.0,
 DTI(1,6)=     0.5,  0.    0.5,  0.5,  3.0, 3.0,
 DTI(1,7)=     0.5,  0.4,  0.5,  0.5,  3.0, 3.0,
 DTI(1,8)=     0.    0.4,  0.,0.,0.,0.,
 BPS(1,1)= 24.,176.,96.,112.,16.,16.,
 BPS(1,2)= 24.,176.,96.,112.,16.,16.,
 BPS(1,3)= 24.,176.,96.,112.,16.,16.,
 BPS(1,4)= 24.,176.,96.,112.,16.,16.,
 BPS(1,5)= 24.,176.,96.,112.,16.,16.,
 BPS(1,6)= 24.,176.,96.,112.,16.,16.,
 BPS(1,7)= 24.,176.,96.,112.,16.,16.,
 BPS(1,8)= 24.,176.,96.,112.,16.,16.,
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TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)

INSTANTANEOUS PARAMETERS AT 1979 2 19 0 0 0 J.D.= 2443923.500000

RADIUS= 72550.000443 VELOCITY= 60.16655
INERTIAL GAMMA=-33.3000 SEPARATION ANGLE= 0.

ENTRY TRAJECTORY ELEMENTS

SEMIMAJOR AXIS=-9.97405289E+05 ECCENTRICITY= 1.05134
PERIAPSIS RADIUS= 51210.1437 VMF= 11.27108
ANGULAR MOMENTUM= 3.648369645E+06 SEMILATUSRECTUM= 1.05049599E+05
ECLIPTIC INCLINATION= 1.91340 EQUATORIAL INCLINATION= 4.03656

ATMOSPHERIC ENTRY CONDITIONS

RADIUS= 72550.000000 INERTIAL VELOCITY= 60.16655
INERTIAL GAMMA= 33.3000 RELATIVE VELOCITY= 49.92717
ENTRY EQUATORIAL LATITUDE= -2.9159
J.D. AT ENTRY= 2443923.500000

VEHICLE ORIENTATION FOR ZERO ANGLE OF ATTACK
-8.53261097E-01 5.21475662E-01 2.93846622E-03

PLANET-SUN VECTOR
5.87873514E-01 -8.08892330E-01 -9.89837004E-03

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 BEGIN PHASE  1        REQUIRED BIT RATE=     0.      BITS/SECOND
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ALTITUDE  50000.0 KM   TIME    0.      HOURS        TIME     .3866 HOURS         TIME     0.      HOURS  VINERTIAL 47.0380 KM/SEC
  RADIUS 121550.0 KM   FROM    0.      MIN           TO    23.195 MIN           IN      0.      MIN    VRELATIVE 37.1829 KM/SEC
                       RX(1)   0.      SEC         TARG 1391.717 SEC          PHASE   0.      SEC    VRADIAL   36.2075 KM/SEC

GAMMI  50.341* DEG     DNRNG   0.      DEG         SZA  38.4885 DEG          ALPHA   2.7853 DEG
GAMMR  76.8469 DEG     TRUAN 262.5812  DEG         SLA 157.4367 DEG          VEH LAT  -.9588 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA        NRPA       H2 PHOTM    HE PHOTM
KM/MEASUREMENT          0.          0.           0.          0.          0.          0.          0.          0.
NO MEAS TOTAL           0.          0.           0.          0.          0.          0.          0.          0.
NO MEAS PHASE           0.          0.           0.          0.          0.          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)        H1   0.        H2   0.        HE   0.
                (IONS)            H1   0.        H2   0.        H3   0.        HE   0.        HEH   0.
-------------------------------------------------------------------------------------------------------------------------
ALTITUDE  48000.0 KM   TIME     .0764 HOURS      TIME     .3182 HOURS         TIME     .0764 HOURS  VINERTIAL 48.9776 KM/SEC
  RADIUS 111550.0 KM   FROM    4.586  MIN           TO    18.618 MIN           IN      4.586  MIN    VRELATIVE 38.6818 KM/SEC
                       RX(1)  275.139  SEC         TARG 1116.578 SEC          PHASE  275.139  SEC    VRADIAL   36.4578 KM/SEC

GAMMI  48.1842 DEG     DNRNG   4.2414  DEG         SZA  42.7279 DEG          ALPHA    .6561 DEG
GAMMR  78.4763 DEG     TRUAN 266.8225  DEG         SLA 157.4367 DEG          VEH LAT -1.2382 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA        NRPA       H2 PHOTM    HE PHOTM
KM/MEASUREMENT          0.          0.           0.          0.          0.          0.          0.          0.
NO MEAS TOTAL           0.          0.           0.          0.          0.          0.          0.          0.
NO MEAS PHASE           0.          0.           0.          0.          0.          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)        H1   0.        H2   0.        HE   0.
                (IONS)            H1   0.        H2   0.        H3   0.        HE   0.        HEH   0.
-------------------------------------------------------------------------------------------------------------------------
ALTITUDE  38000.0 KM   TIME     .1525 HOURS      TIME     .2341 HOURS         TIME     .1525 HOURS  VINERTIAL 51.2185 KM/SEC
  RADIUS 101550.0 KM   FROM    9.152  MIN           TO    14.043 MIN           IN      9.152  MIN    VRELATIVE 40.6574 KM/SEC
                       RX(1)  549.124  SEC         TARG  842.592 SEC          PHASE  549.124  SEC    VRADIAL   36.4935 KM/SEC

GAMMI  45.4483 DEG     DNRNG   9.2972  DEG         SZA  47.7817 DEG          ALPHA    .9220 DEG
GAMMR  63.8425 DEG     TRUAN 271.8784  DEG         SLA 157.4367 DEG          VEH LAT -1.5717 DEG

  INSTRUMENTS        LANG PROBE  MASS SPECT      IRPA        NRPA       H2 PHOTM    HE PHOTM
KM/MEASUREMENT          0.          0.           0.          0.          0.          0.          0.          0.
NO MEAS TOTAL           0.          0.           0.          0.          0.          0.          0.          0.
NO MEAS PHASE           0.          0.           0.          0.          0.          0.          0.          0.

SCALE HEIGHTS   (NEUTRALS)        H1   0.        H2   0.        HE   0.
                (IONS)            H1   0.        H2   0.        H3   0.        HE   0.        HEH   0.
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TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 1 ENTRY ANGLE 33.380 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 20000.0 KM TIME .2289 HOURS TIME .1577 HOURS TIME .2299 HOURS VINERTIAL 57.8361 KM/SEC
RADIUS 91550.0 KM FROM 13.735 MIN TO 9.460 MIN IN 13.735 MIN VRELATIVE 43.1965 KM/SEC
RX(1) 824.121 SEC TAPG 567.595 SEC PHASE 824.121 SEC VRADIAL 36.1522 KM/SEC

GAMMI 42.2137 DEG DNRNG 15.4814 DEG SZA 53.9638 DEG ALPHA 1.7433 DEG
GAMMR 56.8370 DEG TRUAN 278.0625 DEG SLA 157.4367 DEG VEH LAT -1.9629 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	0.	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	0.	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 0. H2 0. HE 0.
(IONS) H1 0. H2 0. H3 0. HE 0. HEH 0.

BEGIN PHASE 2 REQUIRED BIT RATE= 10.6667 BITS/SECOND

ALTITUDE 10000.0 KM TIME .3067 HOURS TIME .0799 HOURS TIME 0. HOURS VINERTIAL 56.8729 KM/SEC
RADIUS 81550.0 KM FROM 18.403 MIN TO 4.793 MIN IN 0. MIN VRELATIVE 46.3723 KM/SEC
RX(1) 1104.161 SEC TAPG 287.556 SEC PHASE 0. SEC VRADIAL 35.1148 KM/SEC

GAMMI 38.1285 DEG DNRNG 23.3265 DEG SZA 61.8868 DEG ALPHA 1.5139 DEG
GAMMR 49.2212 DEG TRUAN 285.9077 DEG SLA 157.4367 DEG VEH LAT -2.4258 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	0.	0.	0.	105.344	105.344	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	0.	0.	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 0. H2 0. HE 0.
(IONS) H1 0. H2 0. H3 0. HE 0. HEH 0.

ALTITUDE 7500.0 KM TIME .3266 HOURS TIME .0600 HOURS TIME .0199 HOURS VINERTIAL 57.7304 KM/SEC
RADIUS 79050.0 KM FROM 19.596 MIN TO 3.599 MIN IN 1.194 MIN VRELATIVE 47.2880 KM/SEC
RX(1) 1175.785 SEC TAPG 215.932 SEC PHASE 71.624 SEC VRADIAL 34.6804 KM/SEC

GAMMI 36.9222 DEG DNRNG 25.6491 DEG SZA 64.1289 DEG ALPHA 1.2414 DEG
GAMMR 47.1711 DEG TRUAN 288.2304 DEG SLA 157.4367 DEG VEH LAT -2.5546 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	0.	0.	0.	104.041	104.041	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	23.875	23.875	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	23.875	23.875	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 0. H2 0. HE 0.
(IONS) H1 0. H2 0. H3 0. HE 0. HEH 0.

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 2 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 5000.0 KM TIME .3468 HOURS TIME .0398 HOURS TIME .0401 HOURS VINERTIAL 58.6301 KM/SEC
RADIUS 76550.0 KM FROM 20.807 MIN TO 2.388 MIN IN 2.404 MIN VRELATIVE 48.2570 KM/SEC
RX(1) 1248.413 SEC TARG 143.304 SEC PHASE 144.251 SEC VRADIAL 34.1471 KM/SEC

GAMMI 35.6206 DEG DNRNG 28.1582 DEG SZA 66.6373 DEG ALPHA .8627 DEG
GAMMR 45.0408 DEG TRUAN 293.7394 DEG SLA 157.4367 DEG VEH LAT -2.6889 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	0.	0.	0.	102.441	102.441	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	48.084	48.084	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	48.084	48.084	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.913 H2 -86.859 H3 -26.194 HE -50.499 HEH -21.521

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.88365E-64		9.01571E-15		4.94277E-71		3.49629E-92		8.12931E-41		3.46737-114
3.75837E-30		1.0000C-140		4.73151E-29		1.67343E-38		9.0157?E-15		1.77828E-59	

ALTITUDE 2500.0 KM TIME .3673 HOURS TIME .0193 HOURS TIME .0606 HOURS VINERTIAL 59.5756 KM/SEC
RADIUS 74050.0 KM FROM 22.039 MIN TO 1.157 MIN IN 3.636 MIN VRELATIVE 49.2828 KM/SEC
RX(1) 1322.311 SEC TARG 69.406 SEC PHASE 218.150 SEC VRADIAL 33.4937 KM/SEC

GAMMI 34.2083 DEG DNRNG 30.8836 DEG SZA 69.3621 DEG ALPHA .3639 DEG
GAMMR 42.8141 DEG TRUAN 293.4648 DEG SLA 157.4367 DEG VEH LAT -2.8290 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	0.	0.	0.	100.481	100.481	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	72.717	72.717	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	72.717	72.717	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.913 H2 -86.859 H3 -26.194 HE -50.499 HEH -21.521

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	5.95542E-25		3.19890E-04		1.39306E-29		9.85388E-42		1.02329E-19		3.46737F-53
2.1[illegible]49E-10		5.62341E-62		1.49624E-07		5.29185E-17		3.19890E-04		3.16228E-27	

BEGIN PHASE 3 REQUIRED BIT RATE= 10.6667 BITS/SECOND

ALTITUDE 2000.0 KM TIME .3715 HOURS TIME .0151 HOURS TIME 0. HOURS VINERTIAL 59.7706 KM/SEC
RADIUS 73550.0 KM FROM 22.288 MIN TO .907 MIN IN 0. MIN VRELATIVE 49.4951 KM/SEC
RX(1) 1337.272 SEC TARG 54.445 SEC PHASE 0. SEC VRADIAL 33.7463 KM/SEC

GAMMI 33.9110 DEG DNRNG 31.4578 DEG SZA 69.9362 DEG ALPHA .2483 DEG
GAMMR 42.3555 DEG TRUAN 294.0391 DEG SLA 157.4367 DEG VEH LAT -2.8577 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	0.	0.	0.	100.039	100.039	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	77.693	77.693	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.913 H2 -86.859 H3 -26.194 HE -50.499 HEH -21.521

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	4.73151E-17		4.12099E-02		2.71624E-21		1.21229E-31		1.69424E-15		5.49541E-41
1.88365E-06		3.16228E-46		4.73151E-05		1.05586E-12		4.12099E-02		8.91251E-21	

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 3 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 1600.0 KM TIME .3731 HOURS TIME .0135 HOURS TIME .0017 HOURS VINERTIAL 59.8401 KM/SEC
RADIUS 73350.0 KM FROM 22.388 MIN TO .807 MIN IN .100 MIN VRELATIVE 49.5807 KM/SEC
RX(1) 1343.275 SEC TARG 48.442 SEC PHASE 6.003 SEC VRADIAL 33.2856 KM/SEC

GAMMI 33.7906 DEG DNRNG 31.6904 DEG SZA 70.1687 DEG ALPHA .2005 DEG
GAMMR 42.1707 DEG TRUAN 294.2717 DEG SLA 157.4367 DEG VEH LAT -2.8693 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	0.	0.	0.	99.857	99.857	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	79.694	79.694	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	2.001	2.001	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.911 H2 -86.859 H3 -26.194 HE -50.499 HEH -21.521

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
6.83912E-14		2.87746E-01		5.62291E-18		1.31704E-27		8.27942E-14		4.16869E-36	
7.16143E-05	6.30957E-40		4.73151E-04		5.54124E-11		2.87746E-01		3.38944E-18		

BEGIN PHASE 4 REQUIRED BIT RATE= 202.6667 BITS/SECOND

ALTITUDE 1600.0 KM TIME .3748 HOURS TIME .0118 HOURS TIME 0. HOURS VINERTIAL 59.9280 KM/SEC
RADIUS 73150.0 KM FROM 22.488 MIN TO .707 MIN IN 0. MIN VRELATIVE 49.6667 KM/SEC
RX(1) 1349.289 SEC TARG 42.428 SEC PHASE 0. SEC VRADIAL 33.2239 KM/SEC

GAMMI 33.6693 DEG DNRNG 31.9247 DEG SZA 70.4030 DEG ALPHA .1518 DEG
GAMMR 41.9851 DEG TRUAN 294.5060 DEG SLA 157.4367 DEG VEH LAT -2.8809 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	0.	16.612	0.	99.672	99.672	0.	0.
NO MEAS TOTAL	0.	0.	0.	0.	81.697	81.697	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.896 H2 -86.859 H3 -26.195 HE -50.499 HEH -21.522

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
9.88553E-11		2.00941E+00		1.16386E-14		1.43067E-23		4.03645E-12		3.16228E-31	
2.72270E-03	1.25893E-33		4.73151E-03		2.90809E-09		2.00941E+00		1.28825E-15		

ALTITUDE 1500.0 KM TIME .3756 HOURS TIME .0109 HOURS TIME .0008 HOURS VINERTIAL 59.9675 KM/SEC
RADIUS 73050.0 KM FROM 22.538 MIN TO .657 MIN IN .050 MIN VRELATIVE 49.7099 KM/SEC
RX(1) 1352.366 SEC TARG 39.416 SEC PHASE 3.011 SEC VRADIAL 33.1927 KM/SEC

GAMMI 33.6083 DEG DNRNG 32.0425 DEG SZA 70.5208 DEG ALPHA .1271 DEG
GAMMR 41.8920 DEG TRUAN 294.6238 DEG SLA 157.4367 DEG VEH LAT -2.8867 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	0.	16.596	0.	99.578	99.578	0.	0.
NO MEAS TOTAL	0.	0.	6.023	0.	82.700	82.700	0.	0.
NO MEAS PHASE	0.	0.	6.023	0.	1.004	1.004	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.865 H2 -86.859 H3 -26.197 HE -50.499 HEH -21.523

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
3.75837E-09		5.31121E+00		5.29390E-13		1.49078E-21		2.41938E-11		8.70964E-29	
1.67880E-02	1.77828E-30		1.49623E-02		2.10672E-08		5.31121E+00		2.51189E-14		

BEGIN PHASE 5 REQUIRED BIT RATE= 250.6667 BITS/SECOND

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 5 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 1450.0 KM TIME .3761 HOURS TIME .9105 HOURS TIME 0. HOURS VINERTIAL 59.9873 KM/SEC
RADIUS 73000.0 KM FROM 22.563 MIN TO .632 MIN IN 0. MIN VRELATIVE 49.7315 KM/SEC
RX(1) 1353.807 SEC TARG 37.910 SEC PHASE 0. SEC VRADIAL 33.1770 KM/SEC

GAMMI 33.5777 DEG DNRNG 32.1016 DEG SZA 70.5798 DEG ALPHA .1146 DEG
GAMMR 41.8454 DEG TRUAN 294.6828 DEG SLA 157.4367 DEG VEH LAT -2.8896 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.589	0.	16.589	0.	99.531	99.531	0.	0.
NO MEAS TOTAL	0.	0.	9.035	0.	83.202	83.202	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.833 H2 -86.859 H3 -26.199 HE -50.499 HEH -21.525

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	2.31739E-04		8.63621E+00		3.56981E-12		1.52154E-20		7.44732E-11		1.44544E-27
4.16869E-02		6.68344E-29		2.66072E-02		5.67032E-08		8.63621E+00		1.10917E-13	

ALTITUDE 1350.0 KM TIME .3769 HOURS TIME .0097 HOURS TIME .0008 HOURS VINERTIAL 60.0270 KM/SEC
RADIUS 72900.0 KM FROM 22.614 MIN TO .582 MIN IN .050 MIN VRELATIVE 49.7748 KM/SEC
RX(1) 1356.823 SEC TARG 34.894 SEC PHASE 3.016 SEC VRADIAL 33.1454 KM/SEC

GAMMI 33.5164 DEG DNRNG 32.2201 DEG SZA 70.6982 DEG ALPHA .0896 DEG
GAMMR 41.7520 DEG TRUAN 294.8013 DEG SLA 157.4367 DEG VEH LAT -2.8954 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.573	0.	16.573	0.	99.436	99.436	0.	0.
NO MEAS TOTAL	6.031	0.	15.066	0.	84.208	84.208	0.	0.
NO MEAS PHASE	6.031	0.	6.031	0.	1.005	1.005	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.689 H2 -86.861 H3 -26.209 HE -50.499 HEH -21.531

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	8.81049E-07		2.28508E+01		1.62204E-10		1.58382E-18		5.19996E-10		3.98107E-25
2.57040E-01		9.44061E-26		8.41381E-02		4.10778E-07		2.28508E+01		2.16272E-12	

ALTITUDE 1250.0 KM TIME .3777 HOURS TIME .0089 HOURS TIME .0017 HOURS VINERTIAL 60.0668 KM/SEC
RADIUS 72800.0 KM FROM 22.664 MIN TO .531 MIN IN .101 MIN VRELATIVE 49.8182 KM/SEC
RX(1) 1359.841 SEC TARG 31.876 SEC PHASE 6.034 SEC VRADIAL 33.1136 KM/SEC

GAMMI 33.4548 DEG DNRNG 32.3389 DEG SZA 70.8171 DEG ALPHA .0643 DEG
GAMMR 41.6584 DEG TRUAN 294.9202 DEG SLA 157.4367 DEG VEH LAT -2.9012 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.557	0.	16.557	0.	99.341	99.341	0.	0.
NO MEAS TOTAL	12.068	0.	21.103	0.	85.214	85.214	0.	0.
NO MEAS PHASE	12.068	0.	12.068	0.	2.011	2.011	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.293 H2 -86.873 H3 -26.236 HE -50.499 HEH -21.548

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	3.34965E-05		6.06048E+01		7.35219E-09		1.64475E-16		3.63078E-09		1.09648E-22
1.58489E+00		1.33352E-22		2.66044E-01		2.97582E-06		6.06048E+01		4.21697E-11	

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 5 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 1150.0 KM TIME .3786 HOURS TIME .0080 HOURS TIME .0025 HOURS VINERTIAL 60.1066 KM/SEC
RADIUS 72700.0 KM FROM 22.714 MIN TO .481 MIN IN .151 MIN VRELATIVE 49.8617 KM/SEC
RX(1) 1362.862 SEC TARG 28.854 SEC PHASE 9.055 SEC VRADIAL 33.0815 KM/SEC

GAMMI 33.3931 DEG DNRNG 32.4583 DEG SZA 70.9364 DEG ALPHA .0387 DEG
GAMMR 41.5646 DEG TRUAN 295.0395 DEG SLA 157.4367 DEG VEH LAT -2.9071 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.541	0.	16.541	0.	99.244	99.244	0.	0.
NO MEAS TOTAL	18.111	0.	27.146	0.	86.221	86.221	0.	0.
NO MEAS PHASE	18.111	0.	18.111	0.	3.018	3.018	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-101.235 H2 -86.948 H3 -26.313 HE -50.499 HEH -21.596

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.27350E-03		1.61781E+02		3.30949E-07		1.69700E-14		2.53513E-08		3.01995E-20
9.77237E+00		1.88365E-19		8.40847E-01		2.15579E-05		1.61781E+02		8.22243E-10	

ALTITUDE 1050.0 KM TIME .3794 HOURS TIME .0072 HOURS TIME .0034 HOURS VINERTIAL 60.1466 KM/SEC
RADIUS 72600.0 KM FROM 22.765 MIN TO .431 MIN IN .201 MIN VRELATIVE 49.9053 KM/SEC
RX(1) 1365.887 SEC TARG 25.830 SEC PHASE 12.080 SEC VRADIAL 33.0491 KM/SEC

GAMMI 33.3311 DEG DNRNG 32.5781 DEG SZA 71.0562 DEG ALPHA .0130 DEG
GAMMR 41.4706 DEG TRUAN 295.1593 DEG SLA 157.4367 DEG VEH LAT -2.9129 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.529	0.	16.525	0.	99.147	99.147	0.	0.
NO MEAS TOTAL	24.159	0.	33.195	0.	87.229	87.229	0.	0.
NO MEAS PHASE	24.159	0.	24.159	0.	4.027	4.027	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1 -98.630 H2 -87.412 H3 -26.538 HE -50.499 HEH -21.718

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	4.84172E-02		4.39294E+02		1.46041E-05		1.72128E-12		1.77011E-07		8.31764E-18
6.02560E+01		2.66073E-16		2.65008E+00		1.56173E-04		4.39294E+02		1.60325E-08	

ALTITUDE 950.0 KM TIME .3803 HOURS TIME .0063 HOURS TIME .0042 HOURS VINERTIAL 60.1466 KM/SEC
RADIUS 72500.0 KM FROM 22.815 MIN TO .380 MIN IN .252 MIN VRELATIVE 49.9490 KM/SEC
RX(1) 1368.914 SEC TARG 22.803 SEC PHASE 15.107 SEC VRADIAL 33.0165 KM/SEC

GAMMI 33.2689 DEG DNRNG 32.6983 DEG SZA 71.1764 DEG ALPHA .0130 DEG
GAMMR 41.3764 DEG TRUAN 295.2795 DEG SLA 157.4367 DEG VEH LAT -2.9188 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.508	0.	16.508	0.	99.049	99.049	0.	0.
NO MEAS TOTAL	30.214	0.	39.249	0.	88.238	88.238	0.	0.
NO MEAS PHASE	30.214	0.	30.214	0.	5.036	5.036	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1 -93.546 H2 -90.313 H3 -27.201 HE -50.499 HEH -21.981

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.84077E+00		1.24137E+03		6.08753E-04		1.67767E-10		1.23595E-06		2.29087E-15
3.71535E+02		3.75837E-13		8.21056E+00		1.13138E-03		1.24137E+03		3.12608E-07	

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 5 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 850.0 KM TIME .3811 HOURS TIME .0055 HOURS TIME .0050 HOURS VINERTIAL 60.2267 KM/SEC
RADIUS 72400.0 KM FROM 22.866 MIN TO .330 MIN IN .302 MIN VRELATIVE 49.9928 KM/SEC
RX(1) 1371.944 SEC TARG 19.772 SEC PHASE 18.137 SEC VRADIAL 32.9935 KM/SEC

GAMMI 33.2064 DEG DNRNG 32.8190 DEG SZA 71.2970 DEG ALPHA .0393 DEG
GAMMR 41.2820 DEG TRUAN 295.4002 DEG SLA 157.4367 DEG VEH LAT -2.9247 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.492	0.	16.492	0.	98.951	98.951	0.	0.
NO MEAS TOTAL	36.275	0.	45.310	0.	89.248	89.248	0.	0.
NO MEAS PHASE	36.275	0.	36.275	0.	6.046	6.046	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1 -89.214 H2-109.885 H3 -29.178 HE -50.499 HEH -22.235

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
6.99842E+01	3.73060E+03	2.16498E-02	1.53754E-08	8.62979E-06	6.30957E-13						
2.29087E+03	5.33884E-10	2.30816E+01	8.19610E-03	3.73062E+03	6.09537E-06						

BEGIN PHASE 6 REQUIRED BIT RATE= 474.6667 BITS/SECOND

ALTITUDE 800.0 KM TIME .3815 HOURS TIME .0051 HOURS TIME 0. HOURS VINERTIAL 60.2467 KM/SEC
RADIUS 72350.0 KM FROM 22.891 MIN TO .304 MIN IN 0. MIN VRELATIVE 50.0148 KM/SEC
RX(1) 1373.461 SEC TARG 18.256 SEC PHASE 0. SEC VRADIAL 32.9670 KM/SEC

GAMMI 33.1751 DEG DNRNG 32.8795 DEG SZA 71.3575 DEG ALPHA .0525 DEG
GAMMR 41.2347 DEG TRUAN 295.4607 DEG SLA 157.4367 DEG VEH LAT -2.9276 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.483	0.	16.483	16.483	98.901	98.901	0.	0.
NO MEAS TOTAL	39.306	0.	48.342	0.	89.753	89.753	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1 -91.490 H2-153.645 H3 -31.290 HE -50.499 HEH -22.098

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
4.31519E+02	6.50512E+03	1.13776E-01	1.46335E-07	2.28034E-05	1.04713E-11						
5.68853E+03	1.99526E-08	3.43040E+01	2.20601E-02	6.50524E+03	2.69153E-05						

ALTITUDE 700.0 KM TIME .3824 HOURS TIME .0042 HOURS TIME .0038 HOURS VINERTIAL 60.2470 KM/SEC
RADIUS 72250.0 KM FROM 22.942 MIN TO .254 MIN IN .051 MIN VRELATIVE 50.0587 KM/SEC
RX(1) 1376.495 SEC TARG 15.221 SEC PHASE 3.035 SEC VRADIAL 32.9337 KM/SEC

GAMMI 33.1123 DEG DNRNG 33.0003 DEG SZA 71.4788 DEG ALPHA .0791 DEG
GAMMR 41.1399 DEG TRUAN 295.5821 DEG SLA 157.4367 DEG VEH LAT -2.9335 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.467	0.	16.467	16.467	98.801	98.801	0.	0.
NO MEAS TOTAL	45.376	0.	54.411	6.070	90.765	90.765	0.	0.
NO MEAS PHASE	6.070	0.	6.070	6.070	1.012	1.012	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-109.859 H2 815.009 H3 -38.389 HE -50.499 HEH -21.241

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
1.64059E+04	1.77869E+04	2.06654E+00	1.47393E-05	1.59221E-04	2.89403E-09						
3.50752E+04	2.81838E-05	4.48153E+01	1.59811E-01	1.77890E+04	5.24807E-04						

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 6 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 600.0 KM TIME .3832 HOURS TIME .0034 HOURS TIME .0017 HOURS VINERTIAL 60.3273 KM/SEC
RADIUS 72150.0 KM FROM 22.992 MIN TO .203 MIN IN .101 MIN VRELATIVE 50.1028 KM/SEC
RX(1) 1379.533 SEC TARG 12.183 SEC PHASE 6.073 SEC VRADIAL 32.9001 KM/SEC

GAMMI 33.0492 DEG DNRNG 33.1227 DEG SZA 71.6006 DEG ALPHA .1060 DEG
GAMMR 41.0450 DEG TRUAN 295.7039 DEG SLA 157.4367 DEG VEH LAT -2.9394 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.450	0.	16.450	16.450	98.700	98.700	0.	0.
NO MEAS TOTAL	51.452	0.	60.487	12.146	91.778	91.778	0.	0.
NO MEAS PHASE	12.146	0.	12.146	12.146	2.024	2.024	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-118.291 H2 181.939 H3 -44.596 HE -50.499 HEH -20.954

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	6.23735E+05		4.21235E+04		2.27053E+01		1.71365E-03		1.11173E-07		7.9432E-07
2.16272E+05		3.98107E-02		3.06842E+01		1.15773E+00		4.21461E+04		1.02329E-02	

ALTITUDE 500.0 KM TIME .3840 HOURS TIME .0025 HOURS TIME .0025 HOURS VINERTIAL 60.3677 KM/SEC
RADIUS 72050.0 KM FROM 23.043 MIN TO .152 MIN IN .152 MIN VRELATIVE 50.1470 KM/SEC
RX(1) 1382.574 SEC TARG 9.142 SEC PHASE 9.114 SEC VRADIAL 32.8662 KM/SEC

GAMMI 32.9860 DEG DNRNG 33.2449 DEG SZA 71.7229 DEG ALPHA .1331 DEG
GAMMR 40.9498 DEG TRUAN 295.8262 DEG SLA 157.4367 DEG VEH LAT -2.9453 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.433	0.	16.433	16.433	98.599	98.599	0.	0.
NO MEAS TOTAL	57.534	0.	66.570	18.228	92.791	92.791	0.	0.
NO MEAS PHASE	18.228	0.	18.228	18.228	3.038	3.038	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-113.029 H2 154.505 H3 -47.534 HE -50.499 HEH -21.134

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	2.37137E+07		9.98112E+04		1.97314E+02		1.98968E-01		7.76247E-03		2.18776E-04
1.33352E+06		5.62341E+01		1.66424E+01		8.38701E+00		1.00007E+05		1.99526E-01	

ALTITUDE 400.0 KM TIME .3849 HOURS TIME .0017 HOURS TIME .0034 HOURS VINERTIAL 60.4081 KM/SEC
RADIUS 71950.0 KM FROM 23.094 MIN TO .102 MIN IN .203 MIN VRELATIVE 50.1912 KM/SEC
RX(1) 1385.619 SEC TARG 6.098 SEC PHASE 12.158 SEC VRADIAL 32.8320 KM/SEC

GAMMI 32.9225 DEG DNRNG 33.3677 DEG SZA 71.8456 DEG ALPHA .1604 DEG
GAMMR 40.8544 DEG TRUAN 295.9489 DEG SLA 157.4367 DEG VEH LAT -2.9512 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.416	0.	16.416	16.416	98.496	98.496	0.	0.
NO MEAS TOTAL	63.623	0.	72.658	24.316	93.806	93.806	0.	0.
NO MEAS PHASE	24.316	0.	24.316	24.316	4.053	4.053	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-108.378 H2 151.340 H3 -48.840 HE -50.499 HEH -21.323

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	9.01571E+08		2.46802E+05		1.56584E+03		2.20844E+01		5.42001E-02		6.02560E-02
8.22243E+06		7.94328E+04		8.62665E+00		6.07585E+01		2.48350E+05		3.89045E+00	

BEGIN PHASE 7 REQUIRED BIT RATE= 914.6667 BITS/SECOND

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 7 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 300.0 KM TIME .3857 HOURS TIME .0008 HOURS TIME 0. HOURS VINERTIAL 60.4487 KM/SEC
RADIUS 71950.0 KM FROM 23.144 MIN TO .051 MIN IN 0. MIN VRELATIVE 50.2356 KM/SEC
RX(1) 1388.666 SEC TARG 3.051 SEC PHASE 0. SEC VRADIAL 32.7976 KM/SEC

GAMMI 32.8587 DEG DNRNG 33.4909 DEG SZA 71.9688 DEG ALPHA .1880 DEG
GAMMR 40.7587 DEG TRUAN 296.0721 DEG SLA 157.4367 DEG VEH LAT -2.9571 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.399	13.119	16.399	16.399	98.393	98.393	0.	0.
NO MEAS TOTAL	69.714	0.	78.750	30.408	94.821	94.821	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-104.121 H2 17.274 H3 32.042 HE -50.499 HEH -21.515

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	3.42764E+10		6.14715E+05		4.06315E+02		2.44612E+03		3.79443E-01		1.65959E+01
5.06991E+07		1.12202E+08		1.46241E-01		4.40157E+02		6.26845E+05		1.00000E+00	

ALTITUDE 280.0 KM TIME .3859 HOURS TIME .0007 HOURS TIME .0002 HOURS VINERTIAL 60.4568 KM/SEC
RADIUS 71830.0 KM FROM 23.155 MIN TO .041 MIN IN .010 MIN VRELATIVE 50.2445 KM/SEC
RX(1) 1389.276 SEC TARG 2.441 SEC PHASE .610 SEC VRADIAL 32.7907 KM/SEC

GAMMI 32.8459 DEG DNRNG 33.5156 DEG SZA 71.9935 DEG ALPHA .1936 DEG
GAMMR 40.7396 DEG TRUAN 296.0968 DEG SLA 157.4367 DEG VEH LAT -2.9583 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.395	13.116	16.395	16.395	98.372	98.372	0.	0.
NO MEAS TOTAL	70.934	1.525	79.969	31.628	95.025	95.025	0.	0.
NO MEAS PHASE	1.220	1.525	1.220	1.220	.203	.203	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.839 H2 4.751 H3 5.441 HE 3.750 HEH 4.168

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	7.09578E+10		7.47120E+05		1.49988E+01		6.09992E+01		5.58213E-01		5.01187E-01
7.29458E+07		4.78630E+08		3.15875E-03		6.42107E+00		7.47184E+05		6.66807E-02	

ALTITUDE 260.0 KM TIME .3861 HOURS TIME .0005 HOURS TIME .0003 HOURS VINERTIAL 60.4649 KM/SEC
RADIUS 71810.0 KM FROM 23.165 MIN TO .031 MIN IN .020 MIN VRELATIVE 50.2534 KM/SEC
RX(1) 1389.886 SEC TARG 1.831 SEC PHASE 1.220 SEC VRADIAL 32.7837 KM/SEC

GAMMI 32.8331 DEG DNRNG 33.5403 DEG SZA 72.0182 DEG ALPHA .1991 DEG
GAMMR 40.7204 DEG TRUAN 296.1216 DEG SLA 157.4367 DEG VEH LAT -2.9595 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.392	13.113	16.392	16.392	98.351	98.351	0.	0.
NO MEAS TOTAL	72.154	3.050	81.189	32.848	95.228	95.228	0.	0.
NO MEAS PHASE	2.440	3.050	2.440	2.440	.407	.407	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.913 H2 5.527 H3 6.482 HE 3.750 HEH 4.174

N(H1	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.46893E+11		9.07402E+05		5.38642E-01		5.03617E-01		8.23379E-01		5.01187E-03
1.04954E+08		2.04174E+09		6.65473E-05		3.10175E-02		9.07403E+05		4.44631E-03	

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 7 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 240.0 KM TIME .3862 HOURS TIME .0003 HOURS TIME .0005 HOURS VINERTIAL 60.4731 KM/SEC
RADIUS 71790.0 KM FROM 23.175 MIN TO .020 MIN N .030 MIN VRELATIVE 50.2623 KM/SEC
RX(1) 1390.496 SEC TARG 1.221 SEC PHASE 1.830 SEC VRADIAL 32.7768 KM/SEC

GAMMI 32.8203 DEG DNRNG 33.5651 DEG SZA 72.0430 DEG ALPHA .2047 DEG
GAMMR 40.7013 DEG TRUAN 296.1463 DEG SLA 157.4367 DEG VEH LAT -2.9606 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.388	13.111	16.388	16.388	98.330	98.331	0.	0.
NO MEAS TOTAL	73.374	4.575	82.410	34.068	95.431	95.431	0.	0.
NO MEAS PHASE	3.660	4.575	3.660	3.660	.610	.613	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -27.487 HE -13.787
(IONS) H1-102.913 H2 5.765 H3 6.812 HE 3.750 HEH 4.256

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	3.04059E+11		1.10205E+06		2.71581E-02		4.28992E-03		1.21451E+00		5.01187E-05
1.51038E+08		8.70964E+09		1.96847E-06		1.49833E-04		1.10205E+06		2.96483E-04	

ALTITUDE 220.0 KM TIME .3864 HOURS TIME .0002 HOURS TIME .0007 HOURS VINERTIAL 60.4812 KM/SEC
RADIUS 71770.0 KM FROM 23.185 MIN TO .010 MIN IN .041 MIN VRELATIVE 50.2712 KM/SEC
RX(1) 1391.106 SEC TARG .610 SEC PHASE 2.440 SEC VRADIAL 32.7698 KM/SEC

GAMMI 32.8075 DEG DNRNG 33.5498 DEG SZA 72.0677 DEG ALPHA .2103 DEG
GAMMR 40.6821 DEG TRUAN 296.1711 DEG SLA 157.4367 DEG VEH LAT -2.9618 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	16.385	13.108	16.385	16.385	98.310	98.310	0.	0.
NO MEAS TOTAL	74.06	6.101	83.630	35.258	95.635	95.635	0.	0.
NO MEAS PHASE	4.881	6.101	4.880	4.880	.813	.813	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1-102.913 H2 5.071 H3 6.876 HE 3.428 HEH 4.730

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	8.83080E+11		1.33844E+06		1.46805E-03		4.63943E-05		1.79143E+00		5.01187E-07
2.17270E+08		3.71535E+10		4.45010E-08		5.15950E-07		1.33844E+06		1.97697E-05	

BEGIN PHASE 8 REQUIRED BIT RATE= 440.0000 BITS/SECOND

ALTITUDE 200.0 KM TIME .3866 HOURS TIME 0. HOURS TIME 0. HOURS VINERTIAL 60.4993 KM/SEC
RADIUS 71750.0 KM FROM 23.195 MIN TO 0. MIN IN 0. MIN VRELATIVE 50.2901 KM/SEC
RX(1) 1391.717 SEC TARG 0. SEC PHASE 0. SEC VRADIAL 32.7629 KM/SEC

GAMMI 32.7947 DEG DNRNG 33.6146 DEG SZA 72.0925 DEG ALPHA .2159 DEG
GAMMR 40.6629 DEG TRUAN 296.1958 DEG SLA 157.4367 DEG VEH LAT -2.9630 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	13.105	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	75.815	7.626	84.851	36.509	95.838	95.838	0.	0.
NO MEAS PHASE	0.	0.	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 2.915 H2 5.076 H3 -4.919 HE 3.428 HEH -5.216

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	3.01995E+12		1.62555E+06		8.02798E-05		1.12292E-06		2.64241E+00		5.01187E-09
3.12608E+08		1.59489E+11		8.64214E-10		1.50672E-09		1.62555E+06		1.31826E-06	

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 8 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 160.0 KM TIME .3868 HOURS TIME -.0002 HOURS TIME .0002 HOURS VINERTIAL 60.4975 KM/SEC
RADIUS 71730.0 KM FROM 23.205 MIN TO -.010 MIN IN .010 MIN VRELATIVE 50.2890 KM/SEC
RX(1) 1392.327 SEC TARG -.611 SEC PHASE .611 SEC VRADIAL 32.7559 KM/SEC

GAMMI 32.7819 DEG DNRNG 33.6394 DEG SZA 72.1173 DEG ALPHA .2215 DEG
GAMMR 40.6437 DEG TRUAN 296.2206 DEG SLA 157.4367 DEG VEH LAT -2.9642 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	13.102	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	75.815	9.153	84.851	36.509	95.838	95.838	0.	0.
NO MEAS PHASE	0.	1.526	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 2.713 H2 5.076 H3 -4.299 HE 3.428 HEH -4.176

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.03276E+13		1.99506E+02		4.34828E-02		5.92141E-04		3.98107E-08		5.01187E-11
4.49780E+08		6.76083E+11		1.68035E-11		4.41171E-12		1.99550E+02		8.79027E-08	

ALTITUDE 160.0 KM TIME .3869 HOURS TIME -.0003 HOURS TIME .0003 HOURS VINERTIAL 60.5056 KM/SEC
RADIUS 71710.0 KM FROM 23.216 MIN TO -.020 MIN IN .020 MIN VRELATIVE 50.2979 KM/SEC
RX(1) 1392.938 SEC TARG -1.221 SEC PHASE 1.221 SEC VRADIAL 32.7489 KM/SEC

GAMMI 32.7690 DEG DNRNG 33.6642 DEG SZA 72.1421 DEG ALPHA .2271 DEG
GAMMR 40.6245 DEG TRUAN 296.2455 DEG SLA 157.4367 DEG VEH LAT -2.9654 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	13.100	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	75.815	10.679	84.851	36.509	95.838	95.838	0.	0.
NO MEAS PHASE	0.	3.053	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 2.916 H2 5.075 H3 21.681 HE 3.428 HEH 28.087

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	3.53183E+13		4.68497E-02		7.30572E-01		1.19892E-02		1.58489E-14		5.01187E-13
6.47143E+08		2.84403E+12		3.26585E-13		1.29805E-14		7.89411E-01		5.86138E-09	

ALTITUDE 140.0 KM TIME .3871 HOURS TIME -.0005 HOURS TIME .0005 HOURS VINERTIAL 60.5138 KM/SEC
RADIUS 71690.0 KM FROM 23.226 MIN TO -.031 MIN IN .031 MIN VRELATIVE 50.3868 KM/SEC
RX(1) 1393.549 SEC TARG -1.832 SEC PHASE 1.832 SEC VRADIAL 32.7419 KM/SEC

GAMMI 32.7562 DEG DNRNG 33.6891 DEG SZA 72.1669 DEG ALPHA .2327 DEG
GAMMR 40.6053 DEG TRUAN 296.2703 DEG SLA 157.4367 DEG VEH LAT -2.9666 DEG

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	13.097	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	75.815	12.206	84.851	36.509	95.838	95.838	0.	0.
NO MEAS PHASE	0.	4.580	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 9.017 H2 5.074 H3 14.795 HE 3.428 HEH 17.667

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.20791E+14		2.96495E-03		1.92301E-01		3.91982E-03		6.30957E-21		5.01187E-15
9.31108E+08		1.23027E+13		6.34266E-15		3.77231E-17		1.99186E-01		3.90441E-10	

TURBOPAUSE DESIGN MISSION 7, RUN 6 (ACTUAL)
PHASE 8 ENTRY ANGLE 33.300 DEG INERTIAL AT 72550.0 KM RADIUS

ALTITUDE 120.0 KM	TIME .3873 HOURS	TIME -.0007 HOURS	TIME .0007 HOURS	VINERTIAL 60.5219 KM/SEC	
RADIUS 71670.0 KM	FROM 23.236 MIN	TO -.041 MIN	IN .041 MIN	VRELATIVE 50.3157 KM/SEC	
	RX(1) 1394.160 SEC	TARG -2.443 SEC	PHASE 2.443 SEC	VRADIAL 32.7349 KM/SEC	
GAMMI 32.7433 DEG	DNRNG 33.7139 DEG	SZA 72.1918 DEG	ALPHA .2383 DEG		
GAMMR 40.5861 DEG	TRUAN 296.2951 DEG	SLA 157.4367 DEG	VEH LAT -2.9674 DEG		

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	13.094	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	75.815	13.733	84.851	36.509	95.838	95.838	0.	0.
NO MEAS PHASE	0.	6.107	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 8.999 H2 5.072 H3 14.742 HE 3.428 HEH 17.619

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	4.13048E+14		3.21930E-04		4.96286E-02		1.26123E-03		2.51189E-27		5.01187E-17
1.33968E+09		5.24807E+13		1.23064E-16		1.10308E-19		5.12118E-02		2.60615E-11	

ALTITUDE 100.0 KM	TIME .3874 HOURS	TIME -.0008 HOURS	TIME .0008 HOURS	VINERTIAL 60.5301 KM/SEC	
RADIUS 71650.0 KM	FROM 23.246 MIN	TO -.051 MIN	IN .051 MIN	VRELATIVE 50.3247 KM/SEC	
	RX(1) 1394.771 SEC	TARG -3.054 SEC	PHASE 3.054 SEC	VRADIAL 32.7279 KM/SEC	
GAMMI 32.7305 DEG	DNRNG 33.7388 DEG	SZA 72.2166 DEG	ALPHA .2449 DEG		
GAMMR 40.5668 DEG	TRUAN 296.3200 DEG	SLA 157.4367 DEG	VEH LAT -2.9689 DEG		

INSTRUMENTS	LANG PROBE	MASS SPECT	IRPA	NRPA	H2 PHOTM	HE PHOTM		
KM/MEASUREMENT	0.	13.091	0.	0.	0.	0.	0.	0.
NO MEAS TOTAL	75.815	15.261	84.851	36.509	95.838	95.838	0.	0.
NO MEAS PHASE	0.	7.635	0.	0.	0.	0.	0.	0.

SCALE HEIGHTS (NEUTRALS) H1 -54.974 H2 -16.266 HE -13.787
(IONS) H1 8.987 H2 5.071 H3 14.711 HE 3.428 HEH 17.567

N(H1)	N(H2)	N(HE)	N(H1+)	N(H2+)	N(H3+)	N(HE+)	N(HEH+)	N(E-)	QE(H1)	QE(H2)	QE(HE)
	1.41254E+15		3.48260E-05		1.27607E-02		4.04490E-04		1.00000E-33		5.01187E-19
1.92752E+09		2.23872E+14		2.38494E-18		3.22558E-22		1.32000E-02		1.73780E-12	

APPENDIX F

GSFC ATMOSPHERIC MODEL

(ATTACHMENT II TO STATEMENT OF WORK)

January 4, 1971

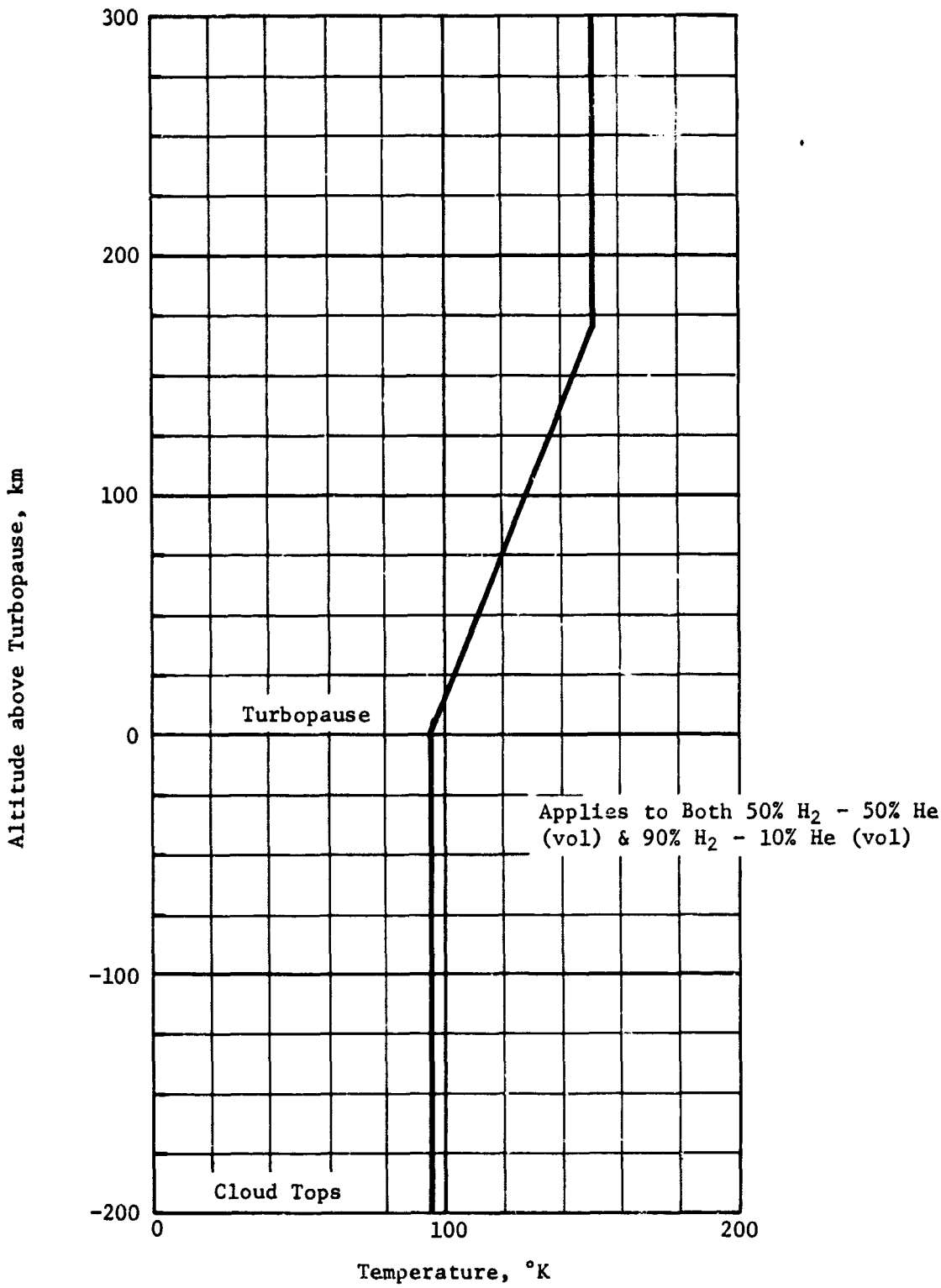


Fig. F-1 Temperature of Jovian Atmospheres

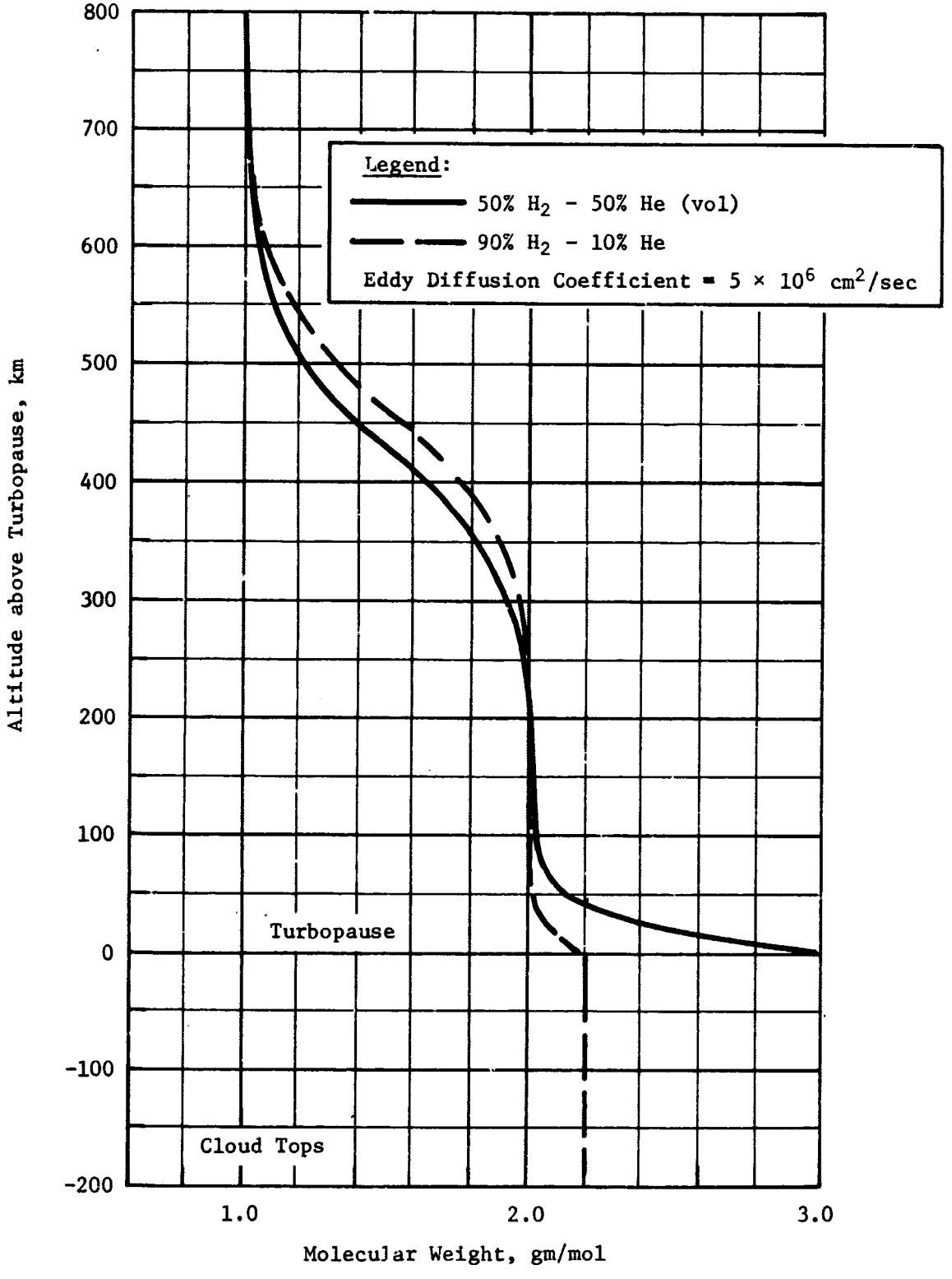


Fig. F-2 Molecular Weight of Jovian Atmospheres

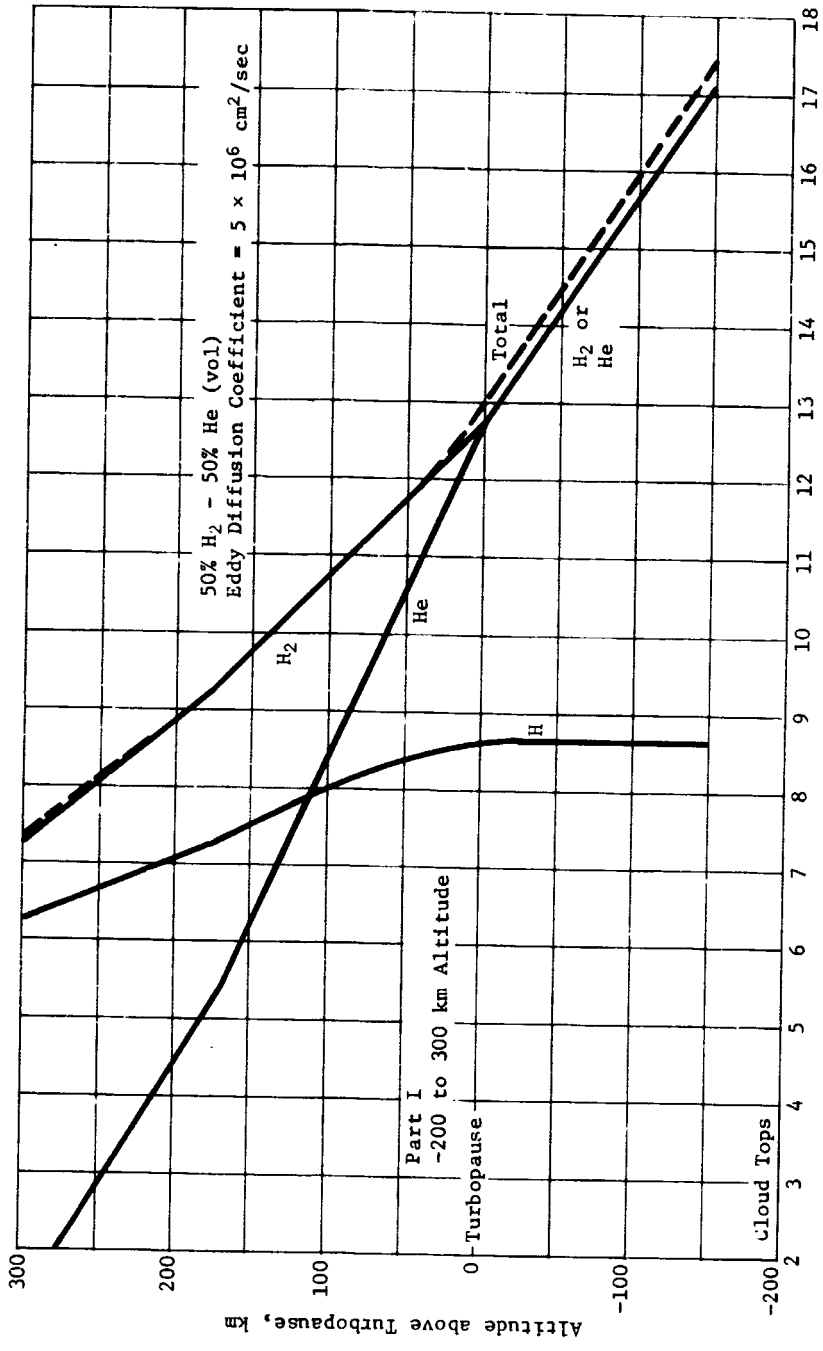


Fig. F-3 Number Densities of Jovian Atmosphere

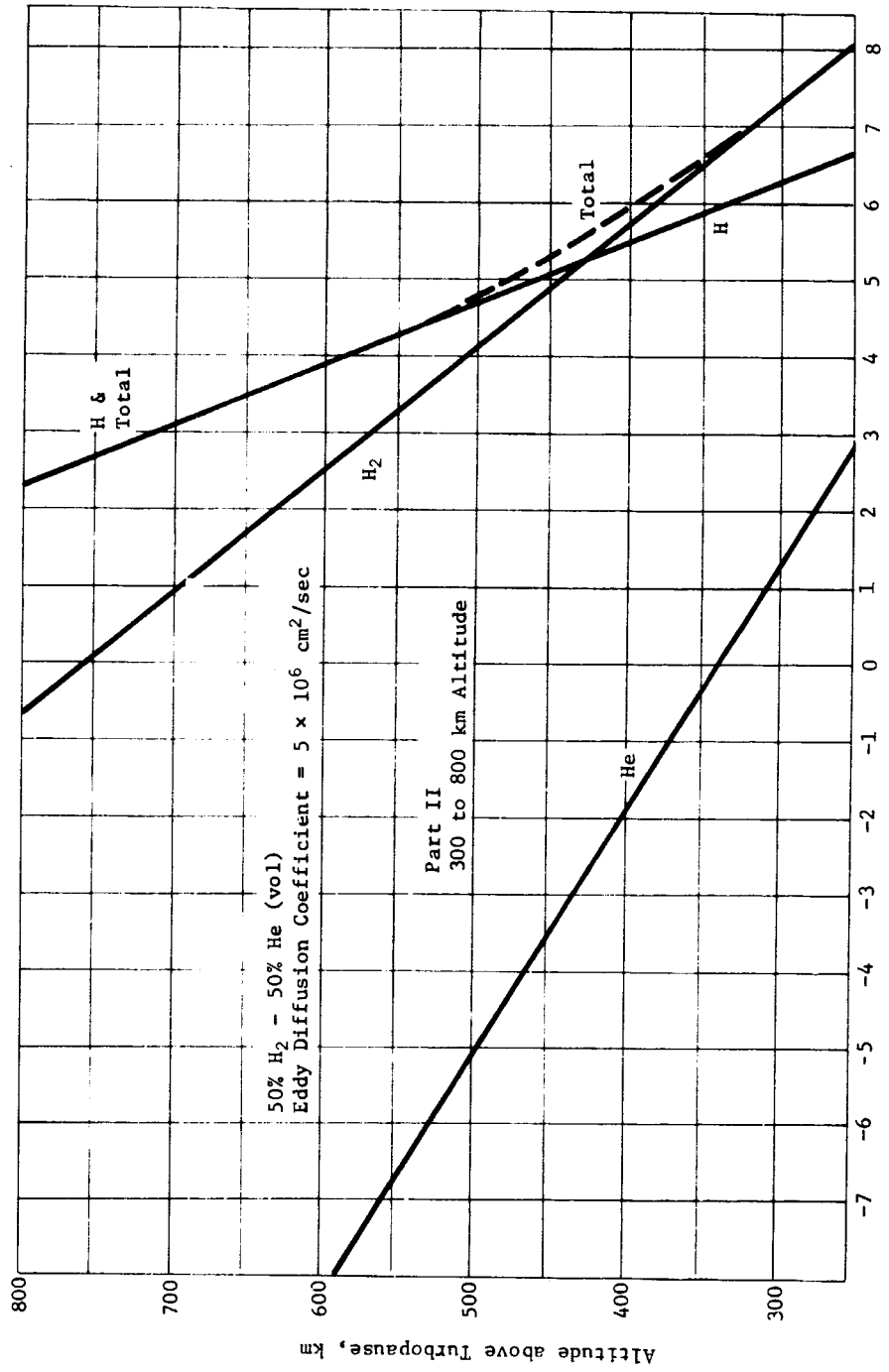


Fig. F-4 Number Densities of Jovian Atmosphere

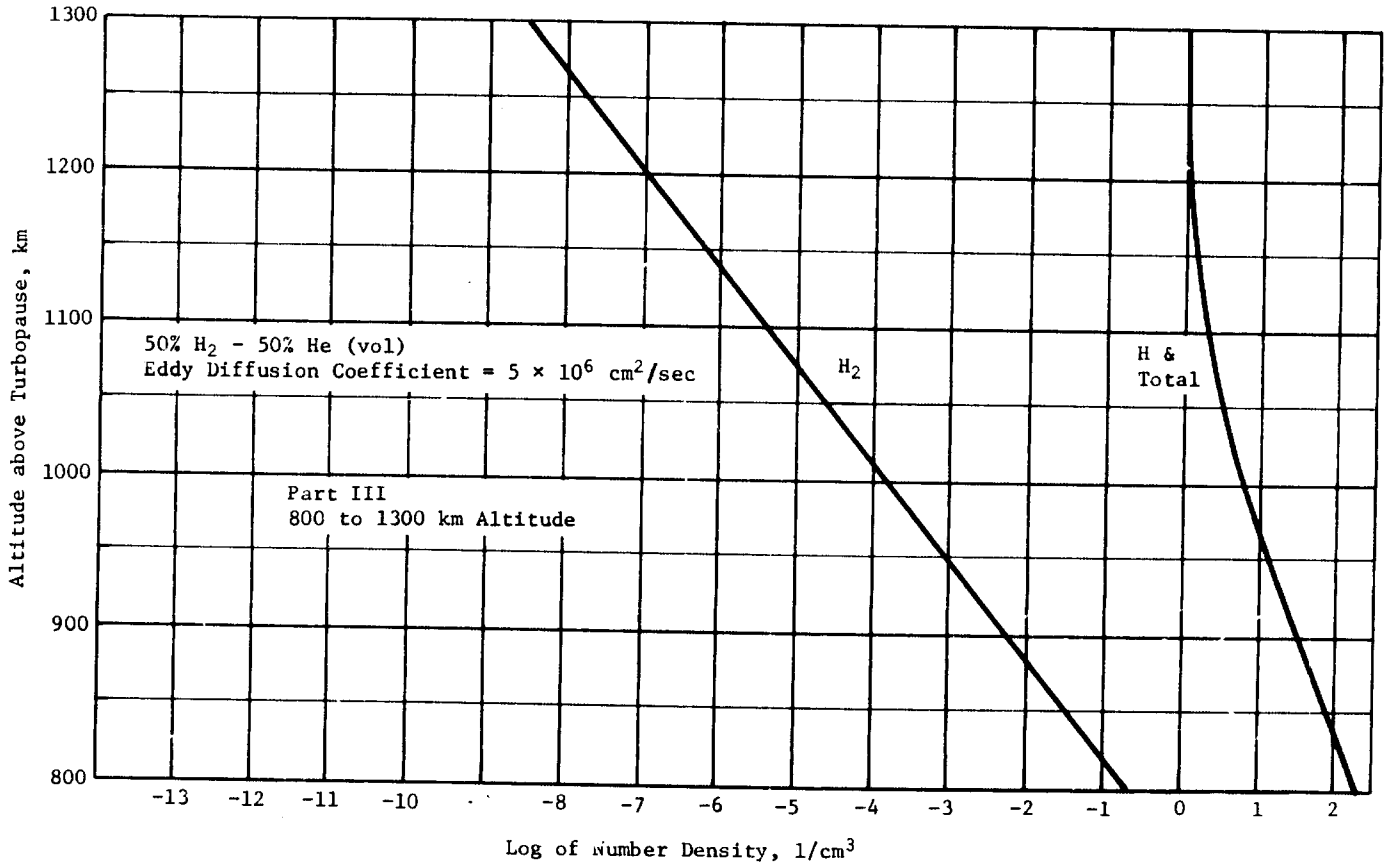


Fig. F-5 Number Densities of Jovian Atmosphere

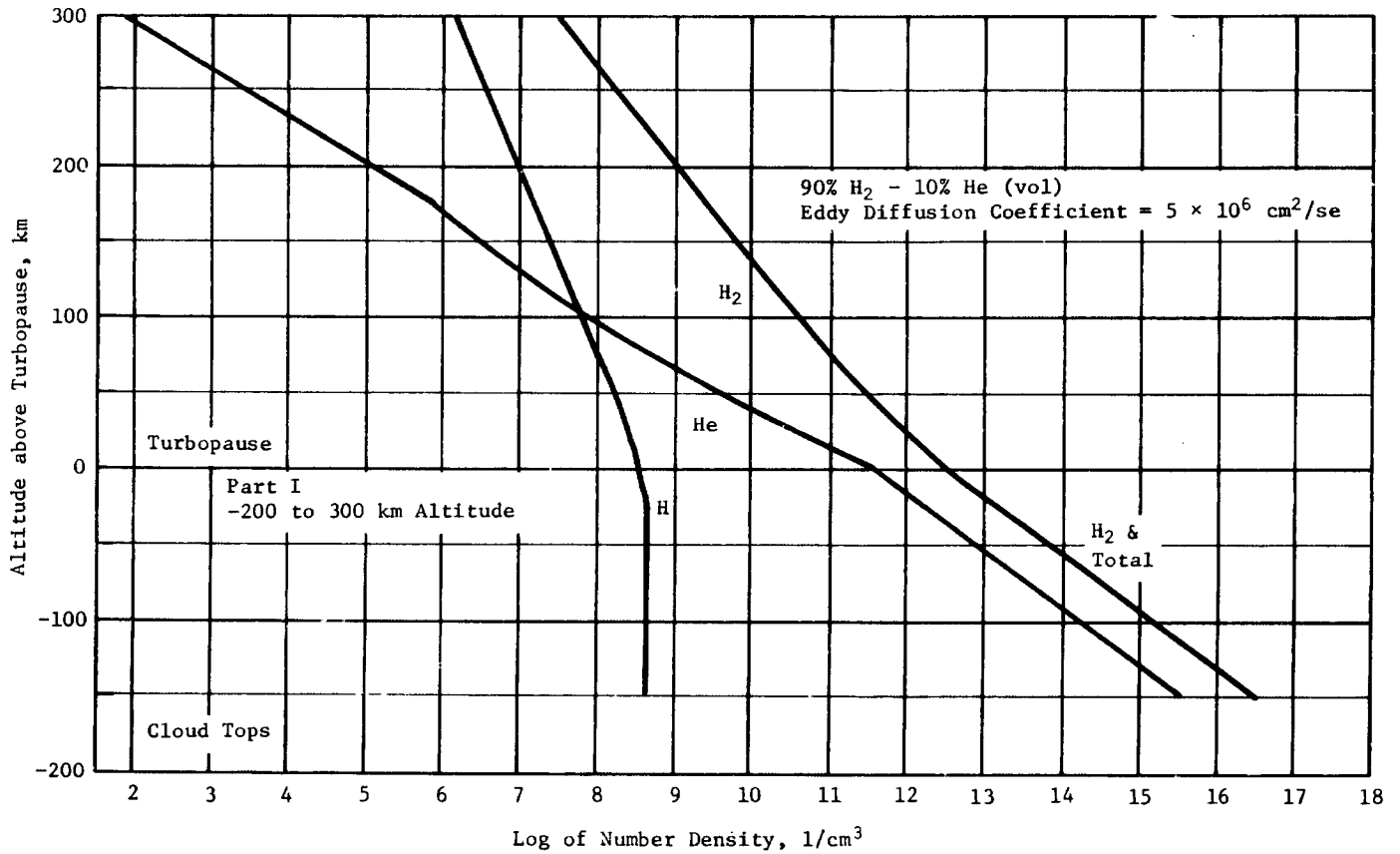


Fig. F-6 Number Densities of Jovian Atmosphere

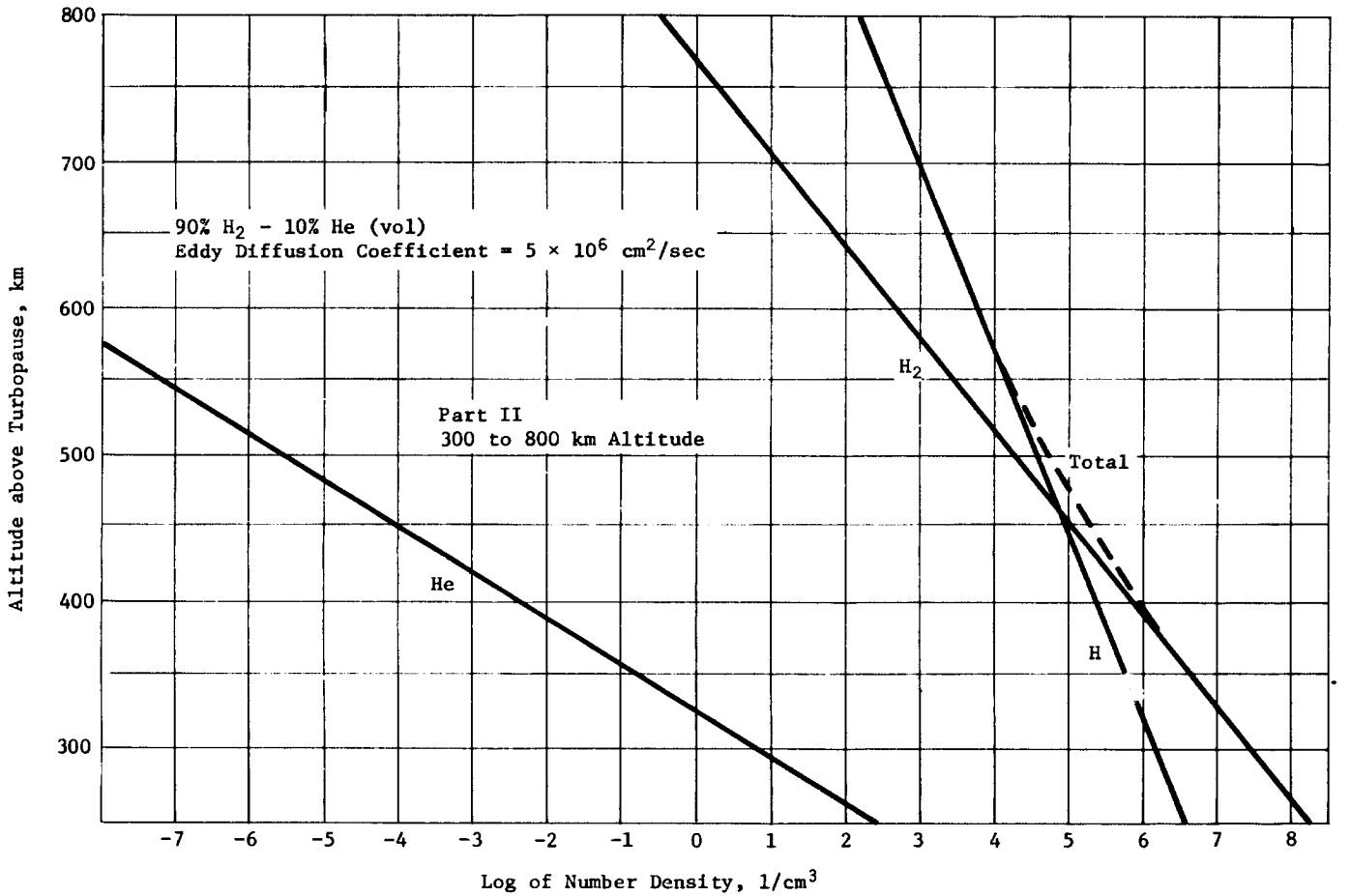


Fig. F-7 Number Densities of Jovian Atmosphere

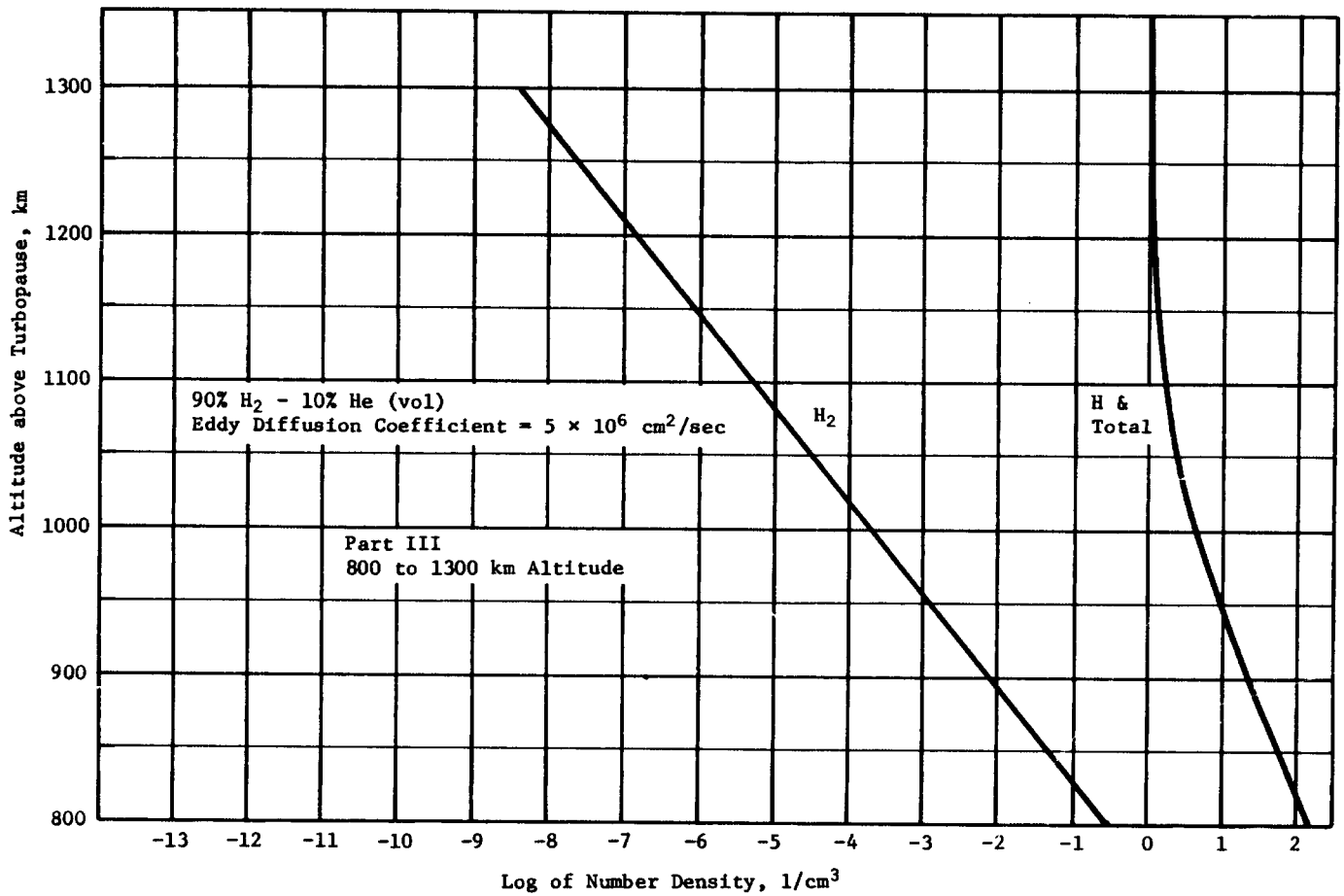


Fig. F-8 Number Densities of Jovian Atmosphere

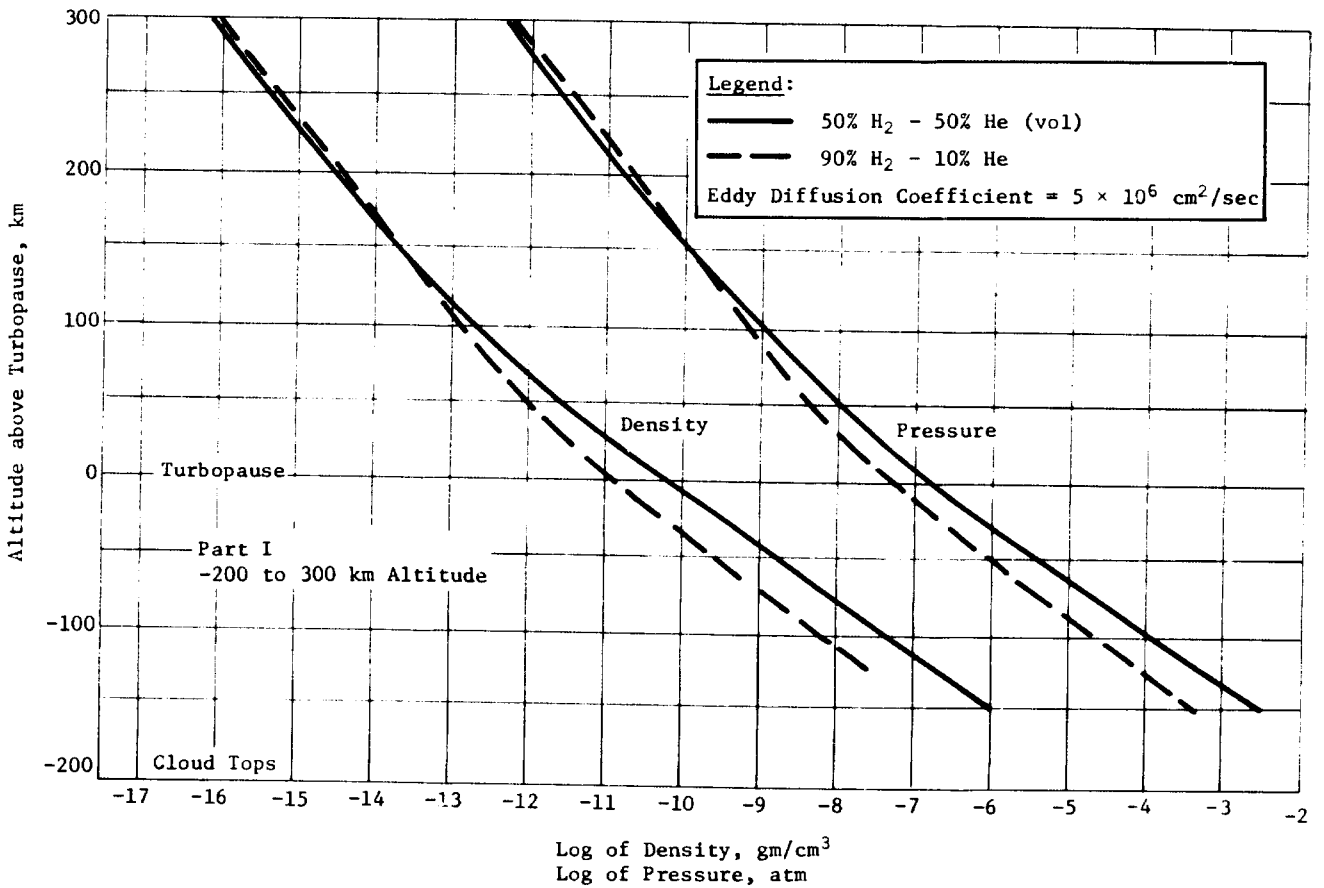


Fig. F-9 Density and Pressure of Jovian Atmosphere

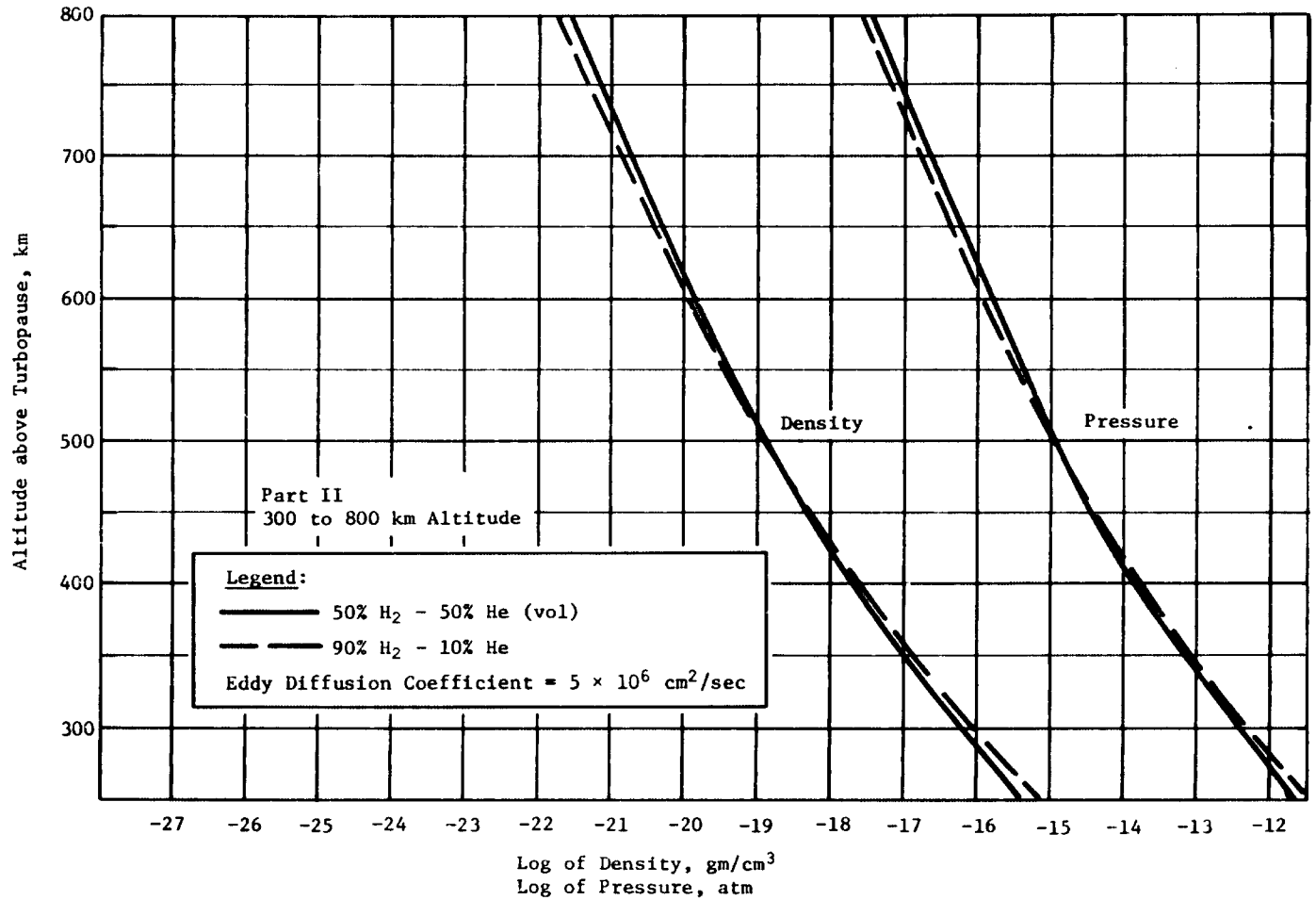


Fig. F-10 Density and Pressure of Jovian Atmosphere

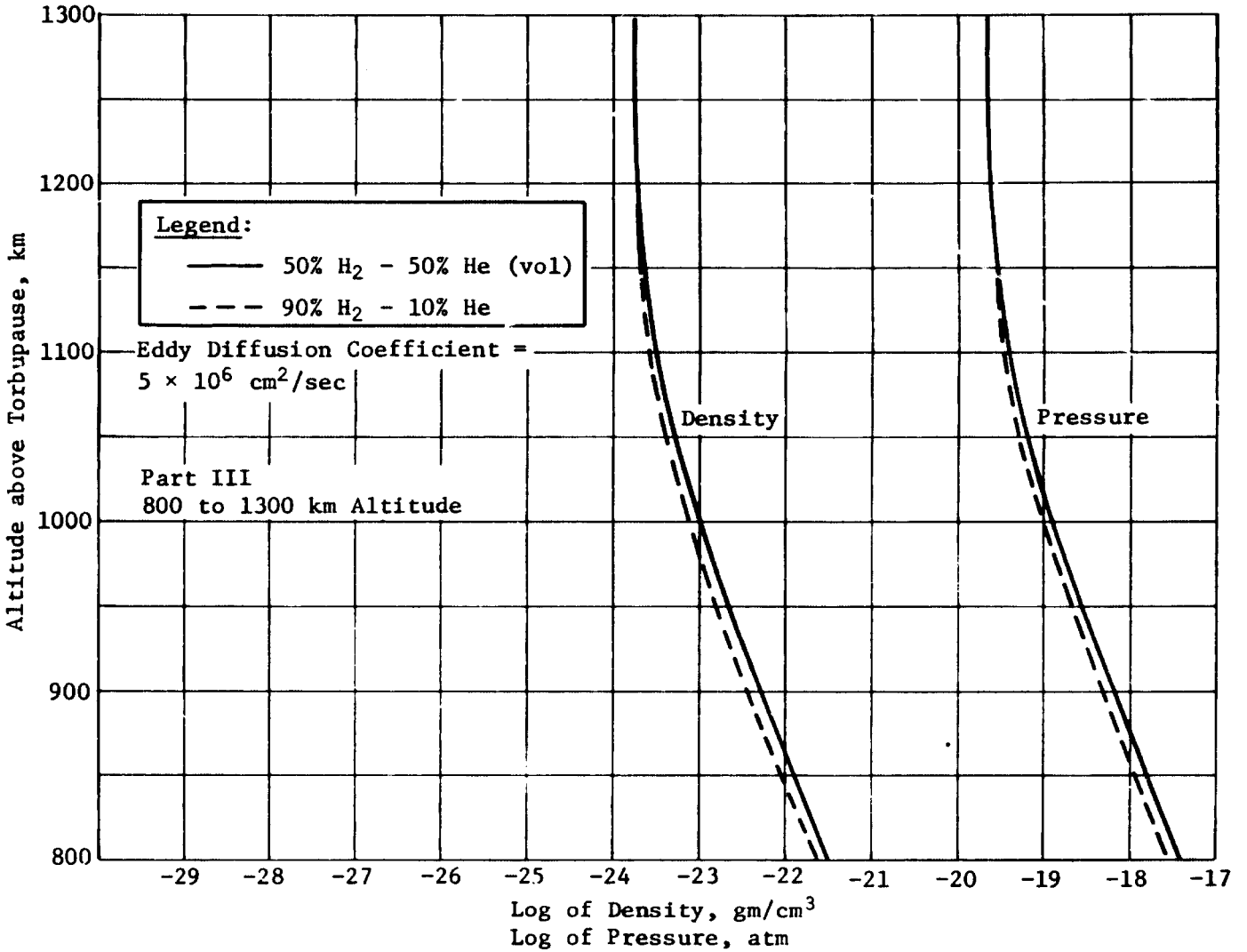


Fig. F-11 Density and Pressure of Jovian Atmosphere

APPENDIX G

PROBE K-BAND POWER SOURCES

R. Compton

January 6, 1972

Preliminary analysis of the atmosphere entry communication blackout problem for the Jupiter Turbopause Probe indicated that frequencies in the K-band region may be required to provide a data link below the turbopause without excessive (> 3dB) attenuation. Lower frequencies will have greater attenuation since plasma attenuation is inversely proportional to the frequency of operation. Therefore, a data transmission system operating at K-band would be necessary if deeper probe penetration were required on some future missions.

1. Vendor Survey

A vendor survey was performed to determine the projected 1975 state-of-the-art for RF power sources in the centimeter region. This survey was necessary to determine the usable upper RF power limit in designing the missions. Both solid state and tube sources were investigated. General industry trends were surveyed along with the feasibility of achieving by 1975 a transmitter with performance characteristics as listed in Table G-1. K-band was chosen because it was the upper frequency considered. Eight suppliers were contacted and six responded to the request. Summaries of their responses follow.

Sperry Electronic Tube Division, Gainesville, Florida - Sperry is presently engaged in development of a traveling wave tube (TWT) to achieve an objective of 50 watts cw from 18.0 to 26.0 GHz. It will be designed for either conduction or air cooling. The gain at rated power will be 30 dB minimum. Sperry anticipates that a demonstration model will be complete by April 1972. The TWT will be periodic permanent magnet focused. Dimensions and weight have not been established but would probably be within 12 × 2 × 2 in. and 5 lb, respectively. The TWT would be designed to serve both ground based and airborne applications. The tube will have a helix interaction circuit to provide the required bandwidth, and is expected to exhibit a minimum of 20% overall efficiency at bandedge power levels rising to over 25% at center frequencies.

The phase and intermodulation characteristics of this tube should be similar to those exhibited by Sperry's other high power TWTs at lower frequency ranges. Minimum power consumption and weight are requirements. In narrower frequency ranges of 1 GHz and less, several techniques such as helix phase tapering and multiple collector depression can raise TWT efficiency to near 40%. However, for greater bandwidths, it would be very speculative to assume more than 30% TWT efficiency by 1978. Power supply efficiency of 85 to 92% would put overall transmitter efficiency somewhere in the 25 to 28% region.

Table G-1. Transmitter Performance Characteristics

PARAMETERS	
Frequency	K-band (18-25 GHz)
RF power output	25 watts cw
Modulation	Phase
Efficiency	Maximum feasible
Primary power	18-26 V dc
Size and weight	Minimum feasible
Life	18 months nonoperating during outer space cruise; 48 hours operating over 15-day period
ENVIRONMENT	
Ambient pressure	10^{-14} torr
Shock	200g, 1 ms
Sine vibration	5-35 Hz, 0.75 g_{rms}
	35-250 Hz, 6 g_{rms}
	250-600 Hz, 4.5 g_{rms}
	600-2000 Hz, 9.0 g_{rms}
	(3 axes, 1 octave per minute)
Random vibration	0.3 g^2/Hz, overall 16 g_{rms}
	60 sec each axis, 3 axes
Thermal vacuum	-20°C, 10^{-6} torr, 2 days; 1 day at +55°C
Decompression	124 torr/sec
Temperature change rate	30°C/hr
Acoustic	150 dB for 2 minutes

Sperry's development plan in solid state microwave devices includes wideband amplifiers to serve many of the applications that now require traveling wave tubes. Power levels of 20 watts at K-band in six to eight years would not seem to be impossible, but they cannot comment with any assurance on efficiency and the other characteristics that would be vital to our application.

General Electric Company, Owensboro, Kentucky - GE has made a recent study of the available and theoretically available performance from solid state sources, and 20 watts appears to be beyond the present state of the art. The 1975 predicted singlechip performance was in the 5-watt area, which is still short of the requirements. The industry proposes 4 watts at 12 GHz which should be available soon. This is a Fairchild development. It uses parallel and/or series operation to obtain the power output. This suggests that 20 watts may be available in the future from a composite source using hybrid power "trees" to couple several diodes to one output port.

EMR Telemetry, Sarasota, Florida - A search of microwave literature indicates that technology is available to produce 20 watts cw in the band of 18 to 25 GHz at the present time. This can be accomplished by use of a power oscillator operating at the desired output frequency, or by generating a low power signal which is then used to drive an amplifier that has the gain and desired power output capability at the output frequency.

In either of these cases, electron tubes would be required. The power oscillator might be either a backward wave oscillator or a multicavity klystron, and the power amplifier could be either a traveling wave tube or a multicavity klystron.

At this time there appears to be no practicable way that 20 watts of cw power can be produced over this frequency range by solid state methods. Present varactor diodes that operate at these frequencies have a very low reverse voltage capability; therefore they have a very low power capability. Solid state diodes that can generate power directly at the frequency are also severely power limited.

A breakthrough in the solid state field may make powers in the order of 20 watts at K-band available by 1978, but at the moment there is no way of predicting the characteristics of such a system. For this reason, our predictions will be made on the basis of further development of electron tubes for the production of high power at K-band.

The projected transmitter would use a diode oscillator to produce a low level signal at the output frequency. This low level signal would be stabilized by sending part of the signal to a discriminator, also operating at the output frequency, where any frequency deviation would produce an error signal. This error signal would be used to keep the output frequency within the desired tolerance.

The low level signal would be amplified to the desired level of 20 watts in a TWT amplifier. Phase modulation could be accomplished by the variation of one of the potentials applied to the TWT. It is estimated that the overall efficiency of such a transmitter would be in the order of 8 to 10%, the primary power required would be about 250 watts, and the size 0.15 ft^3. The weight would be 10 lb maximum.

Except for the 18 months in space, the environmental requirements are not stringent. The best means of ensuring operation after 18 months in space might require a slow leak in the transmitter housing to permit the evacuation of the housing during the 18 months without the danger of refilling with Jupiter's atmosphere during entry.

EMR is developing a solid state S-band transmitter in which the power is developed by an oscillator operating at the output frequency. This oscillator is stabilized by sending part of the oscillator signal to a discriminator which operates at a harmonic of the output frequency. The error signal developed in the discriminator is used in a closed loop system to reduce the undesired frequency deviation of the S-band oscillator. The experience gained in this development program should be helpful in developing a closed loop control system for a K-band oscillator.

Hughes Electron Dynamics Division, Torrance, California - Hughes Electron Dynamics Division presently manufactures traveling wave tubes that supply 20 watts at 14 GHz. This tube is designated the Hughes Model 851H and is used in the Skylab Program. Hughes also has traveling wave tubes that deliver 10 watts at 18 GHz. They see no problem in extending performance to 20 watts at 18 to 25 GHz (Figure G-1) with high reliability.

In the past several years, efficiency achievable in a TWT has increased in the range of 35% to a measured 60% at narrow band. High efficiency at K-band is still difficult because of high circuit losses and the small size of the helix. Hughes expects to achieve 50% efficiency in 1972 over a band centered at 6 GHz and, based on this, can confidently project an efficiency of 40% at K-band by 1978 to 1980. The size will be determined by the required gain; however, for a 40-dB gain tube, weight would be approximately

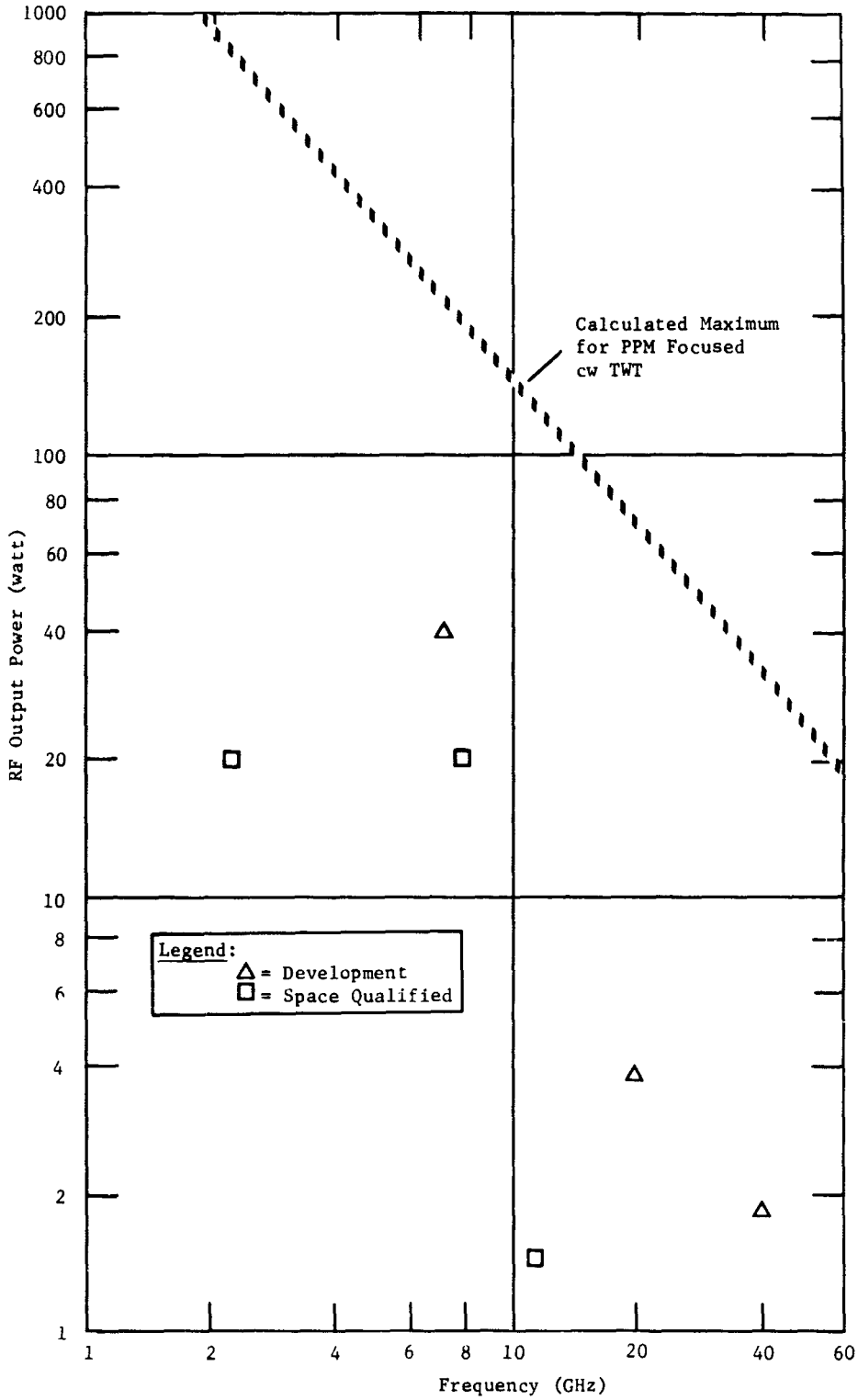


Figure G-1. Hughes TWT Performance

1.25 lb. Power supply efficiency would be in the order of 85 to 90%. The complete package, tube and power supply would weigh approximately 10 lb and would measure 3.5 × 5.0 × 10 in. The length would be dependent upon gain of the tube. Regarding the environmental requirements, present hardware will meet these specifications.

Conic Corporation, San Diego, California - By using a Gunn source and hybrid combining techniques of Impatt amplifiers, it is Conic's opinion that 20 watts will be achievable using solid state techniques in the 1978 to 80 time frame. It is also quite possible that there will be Trapatt diodes available for high power generation at K-band. At present, the GaAs Impatt diode shows the greatest promise for high cw output. The achievable efficiency will be in the 15 to 20% region. Primary power requirements will still be in the 60 to 90 V dc region. Strip line circuit techniques will reduce overall weight to 7 to 10 lb and occupy 100 to 150 in^3. The environmental requirements are no more severe than those imposed on present day transmitters.

Watkins-Johnson Company, Palo Alto, California - Watkins-Johnson stated that the requirements listed in Table G-1 could be met by a TWT amplifier using present design techniques. They presently have a line of TWTs (WJ-231 series) in development that have a saturated power output of 35 watts cw at 8 GHz(X-band). The overall efficiency is 28% and the weight is 2.5 lb. The noise figure is 30 dB maximum and has a VSWR of 1.4 to one.

For K-band the projected design details include an overall efficiency of 30%, primary power input for 20 watts output is 68 watts, overall weight (amplifier + power supply) is 7.5 lb, and will meet all the environmental requirements.

2. Literature Survey

A literature survey was also conducted to obtain a more objective opinion on the projected state of the art for K-band RF power sources in the 1975 to 1978 time frame. Design approaches are divided into two categories: microwave tubes and solid state devices. Microwave tubes include only two devices; the solid state category is more general and includes a broad range of devices. Performance characteristics of the principal RF sources are shown in Figure G-2 and will be discussed in detail.[1]

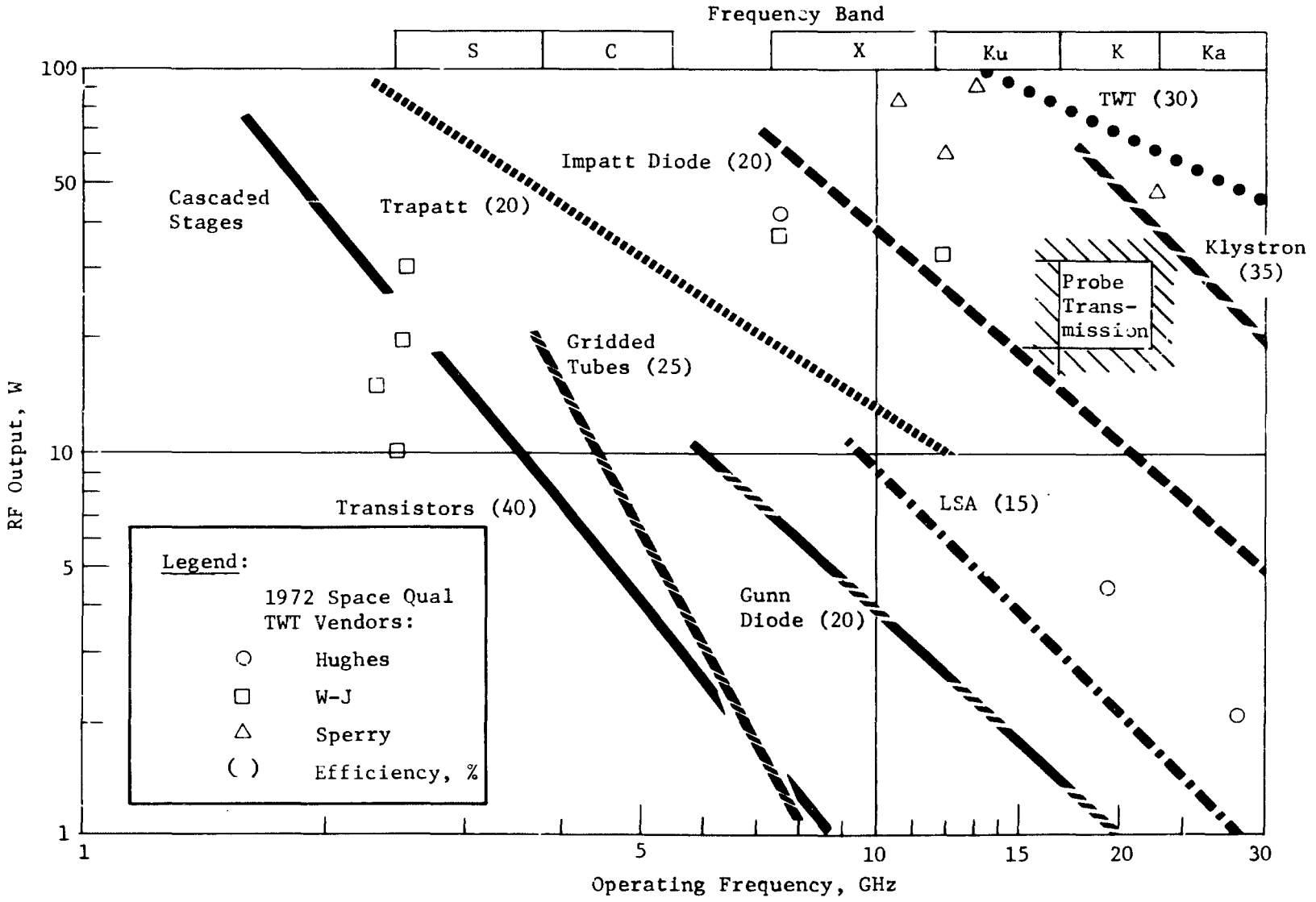


Figure G-2. Projected 1975 RF Power Source Capability

Microwave Tubes - The reduced performance of standard grid-controlled vacuum tubes in the microwave region has fostered development of other types of tubes for use as amplifiers. Such tubes function on the basis of the modulation of the velocity of an electron stream rather than on its density. Microwave tubes are divided into linear beam and crossed-field devices. The principal types of linear beam tubes are the klystron, the TWT, and the backward-wave oscillator (BWO). Crossed-field tubes include the magnetron oscillator and carcinotron oscillator. The magnetron requires a strong magnetic field to develop the required power which would interfere with the science instruments on the probe and therefore was not considered further. Carcinotrons are basically a laboratory device that have an inherently high noise level with spurious power output, often not more than 10 to 15 dB below the main signal output.[2] Therefore, carcinotrons were not considered further for probe transmitter applications. The BWO is generally a low-power device, with 50 mw being typical; it is not suitable for high-power applications.

Of the several types of microwave tubes, only the klystron and TWT are possible candidates for the transmitter. Multicavity klystron amplifiers find considerable application for high-power cw power systems. Average powers of 1 watt or greater are presently available at X-band with an efficiency of 40%. Klystrons have the disadvantage of restricted bandwidth, high beam voltage (enhances RF breakdown during atmospheric entry), and frequency instability. The 20-watt klystrons must also be liquid cooled for best results and are electrostatically focused.[3]

A TWT differs from a klystron in that the RF field is not confined to a cavity but is distributed along a wave-propagating structure. An electron gun produces a longitudinal beam of electrons that interacts with the field of a wave traveling along the structure. Spaced closely around the beam is a helix that propagates slow wave (Phase velocity is appreciably less than the velocity of light). An external RF signal is coupled into the tube where its longitudinal component interacts with the electron beam. Mutual interaction exists between the electron stream and the wave with the net result that dc energy is released by the electron stream to the circuit as RF energy, and the wave is thus amplified. TWTs are designed to operate in the power saturation region since efficiency is highest at that point. Raising the input power above the saturation point will lower the RF output power and efficiency.[4],[5]

TWTs have a broader bandwidth than klystrons, typically 1 GHz, and have a phase linearity of ±3 deg over any 10-MHz bandwidth within the frequency range of the tube. A TWT has a longer life span than a klystron. Presently, TWT efficiency is slightly lower than for a klystron, but TWT suppliers are actively working on raising tube efficiency to levels of 40% or greater. Much of this impetus stems from the growing need for high power tubes for space applications.

Much of the power wasted in a TWT is in the form of heat generated by the impact of beam electrons with the collector structure. Velocity tapering is used at the collector to reduce electron impact velocities through multistage collector depression (MSCD). One of the advantages of collector depression is that it lowers the demands on high voltage power supplies. Heat dissipation in space is generally accomplished by conduction and radiation. The use of heat pipes for thermal control in a space vehicle will be tried for the first time in a tube being developed by Hughes.[6]

Hardware development activity is increasing to develop a 12-GHz tube producing about 20 watts for the newly authorized K-band channel for Comsat and Intelsat-5. It is interesting to note that all tube suppliers are proposing TWTs for this application in lieu of klystrons.[7] This coincides with the recommendations developed from the vendor survey conducted for the probe study considering TWTs. Klystrons or solid state devices were not recommended by any supplier.

Solid State Devices - Two trends are putting solid state devices into microwave circuits in increasing numbers: (1) the increased use of integrated circuits leading to smaller, lighter, and more rugged equipment; (2) the increased capability of solid state devices to perform at these frequencies.[8] As mentioned in the vendor summaries, the state of the art for solid state devices for 1975 is not predicted to have high power RF amplifiers available at K-band as reliable, space qualified production items. Industry emphasis is on the more popular communication bands (X and S) which are lower in frequency.[9] Several devices that show promise of operation in the microwave region exist. These devices will be summarized briefly.

Diodes that operate under the transferred-electron bulk effect using GaAs operate up to 35 GHz, but presently only have power outputs of 0.5 watt or less. Gunn-effect devices have their best performance at higher frequencies than do transistors. The extrapolated 1975 cw Gunn-effect capability is presented in Figure G-2.[10]

Semiconductors operating at microwave frequencies are transit-time limited. With single-chip power silicon transistors, 5 watts at 2 GHz have been obtained. Germanium planar-signal transistors are also being developed. Conversion efficiency is a critical factor. Projected 1975 data on power versus frequency is plotted in Figure G-2. X-band is the projected upper limit with an efficiency of 40% and producing 1 or 2 watts.

Limited space charge accumulation (LSA) devices of bulk GaAs oscillate because they exhibit a negative-resistance characteristic and are not transit-time limited. They reach a peak in both output and efficiency above 8 GHz with an upper limit at 500 GHz. They are presently a low-power device and have produced a peak power of 50 watts at X-band. The average cw power is 5 watts. Figure G-2 depicts the performance of LSA devices for 1975.[11,12]

Another device that exhibits a negative resistance and avalanche breakdown is the impact avalanche transit time (Impatt) diode. The fundamental limit for these devices is about 20 watts at K-band, which has not been reached to date. Efficiencies as high as 25% appear possible with a 1975 projected efficiency of 20%, as seen in Figure G-2.[13,14]

Since the anomalous mode or trapped plasma avalanche triggered transit (Trapatt) mode of avalanche diode operation was discovered only about three years ago, sufficient trends have not been established to accurately extrapolate performance to 1975. Progress is being made in extending the frequency of operation of such devices. 2.4 watts cw were generated at S-band in 1970 with an efficiency of 20% using silicon. Theoretical efficiencies are in the region of 50 to 60%. RCA has predicted a capability at 10 GHz of 100 watts cw with 50% efficiency. This device may offer the best means of competing with tubes on a realistic cost per watt basis during the next decade.[12,15]

A combination of two solid state devices also offers possibilities. A Gunn diode master oscillator, frequency locked and modulated by a varactor diode, followed by an Impatt diode to amplify the signal could be used. Approximately 5 watts is projected for the 1975 time period at about 15 to 25% efficiency per Impatt diode. Several devices can be cascaded to provide a higher total RF power. In the normal failure mode, an Impatt diode produces a momentary short circuit (a few milliseconds) followed by an open circuit. Therefore, loss of any one diode will result only in the loss of power contributed by that circuit element.

Conclusion

As can be seen from vendor responses and the literature survey, the best candidate for a K-band RF power amplifier in the 20- to 25-watt region is a traveling wave tube amplifier (Figure G-2). As seen from the illustration, 25 watts at K-band does not exceed the tube state of the art, and the 1975 projected solid state capability may also meet the power requirements.

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APPENDIX H

COMPUTATIONAL PROCEDURE FOR INVISCID FOREBODY FLOW FIELD

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March 3, 1972

The inviscid body flow field is defined as that region bounded by the bow shockwave and the body boundary layer. As noted in Figure H-1, the flow field is composed of a subsonic region and a supersonic region. In the nose cap (subsonic) flow, the governing partial differential equations are elliptic, and in the afterbody (supersonic) region they are hyperbolic. Therefore, different computational techniques are used to describe the two flow fields with suitable matching procedures applied at the sonic line. The details of this computational method are presented in this appendix, following a description of the nonequilibrium thermochemistry model.

THE THERMOCHEMICAL MODEL

The gas in the inviscid shock layer consists of N_c monatomic and diatomic species, including ions and electrons. For this analysis, the species are H, He, e, H_2, H^+, and He^+; however, the method to be described could be applied to any such gas mixture. Each component of the gas is assumed to be thermally perfect. Thus, the equation of state for the gas mixture may be written

$$P = \rho RT \sum_{j=1}^{N_s} \gamma_j \qquad [H\text{-}1]$$

where $R = 8.3134 \times 10^7$ ergs/mole-°K is the universal gas constant, γ_j = the species molal concentration in mole/gm, ρ is the gas density, and P and T are the gas pressure and temperature, respectively. The caloric equation is written in the form

$$h_j = h_j^0 + \varepsilon_j + I_j \qquad [H\text{-}2]$$

where ε_j is the vibrational energy, h_j^0 is the heat of formation, and I_j represents the energies of translation, rotation, and electronic exitation. Therefore the I_j term expands to

$$I_j = \left[\frac{(5 + 2)\eta_j - 1}{2}\right] RT + \left[\frac{\sum_{\ell=1}^{m} \varepsilon_{j\ell} g_{j\ell} e^{-\varepsilon_{j\ell}/T}}{\sum_{\ell=1}^{m} g_{j\ell} e^{-\varepsilon_{j\ell}/T}}\right] \qquad [H-3]$$

where η_j denotes the number of atoms per molecule of the j^{th} species, $\varepsilon_{j\ell}$ is the energy of the ℓ^{th} electronic level, $g_{j\ell}$ is the degeneracy of this level, and m is the number of electronic levels being considered.

The chemical potential $\left(u_j^0\right)$ of the j^{th} species is given by the equation

$$\frac{u_j^0 - h_j^0}{T} = -\left\{b_j + \left(\frac{3 + 2\eta_j}{2}\right) \ell n\, T + \left(\eta_j - 1\right) \ell n \left(1 - e^{\theta_{r_j}/T}\right) + \ell n \left[\frac{\sum_{\ell=1}^{m} g_{j\ell} e^{-\varepsilon_{j\ell}/T}}{g_{j1}}\right]\right\} \qquad [H-4]$$

The constant, b_j, includes the translational and rotational contributions, in addition to the logarithm of the ground-state degeneracy, and may be expressed as,

$$b_j = \ell n \left[2.56033 \times 10^{-2}\, m_j^{3/2}\, g_{j1} / \theta_{r_j}^{\eta_j - 1}\right] \qquad [H-5]$$

where m_j is the molecular weight of the j^{th} species, and θ_{r_j} is the characteristic rotational temperature of the j^{th} species.

For species in vibrational equilibrium, the simple harmonic oscillator approximation,

$$\varepsilon_j = R\theta_{v_j}\left(\eta_j - 1\right) \Big/ \left[e^{\theta_{v_j}/T} - 1\right] \qquad [H\text{-}6]$$

is used for the calculation of vibrational energy of the j^{th} species. Note that θ_{v_j} is the characteristic vibrational temperature of the j^{th} species. The rate of change of concentration of the j^{th} chemical species along a given streamline, s, in the flow field is governed by two equations,

$$\partial\gamma_j \Big/ \partial s = \sum_{i=1}^{N_R} \frac{Q_{ij}}{\rho u}, \qquad j = N_c + 1, N_c + 2, \ldots, N_s \qquad [H\text{-}7]$$

$$\sum_{j=1}^{N_s} \alpha_{jk} \frac{\partial\gamma_j}{\partial s} = 0, \qquad k = 1, 2, \ldots, N_c \qquad [H\text{-}8]$$

where N_c represents the number of elemental species and α_{jk} is the number of atoms of the k^{th} element in the j^{th} species, and N_R is the number of chemical reactions. Conservation of electric charge is assured by assigning $\alpha_{jk_e} = -1$ if the j^{th} species is a positive ion. Note that the convention for ordering chemical species in the model lists the monatomic elements first, followed by the molecular species and ions. Note also that in this ordering, the electron is considered an elemental species.

1. Chemical Reactions in the Flow Field

The set of chemical reactions may be represented by the expression

$$\sum_{j=1}^{N_s} \nu_{ij} M_j \underset{k_{b_i}}{\overset{k_{f_i}}{\rightleftharpoons}} \sum_{j=1}^{N_s} \nu_{ij}^{*} M_j, \qquad i = 1, 2, \ldots, N_R \qquad [H\text{-}9]$$

where M_j represents the j^{th} chemical species in the reaction, ν_{ij} and ν_{ij}^* are respectively the stoichiometric coefficients of the j^{th}-reactant and the j^{th}-product in the i^{th} reaction, and k_{f_i} and k_{b_i} are the forward and backward reaction rates for the j^{th} reaction. Note that N_R is the number of chemical reactions in the system, and j is the number of chemical species being considered.

The forward and backward rate constants are related by

$$\frac{k_{f_{i_{eq}}}}{k_{b_{i_{eq}}}} = (RT)^{-\left[\sum_{j=1}^{N_s}\left(\nu_{ij}^* - \nu_{ij}\right)\right]} \exp\left[-\frac{\Delta F_i^0}{RT}\right] \qquad [H\text{-}10]$$

where ΔF_i^0 is the change in free energy in the i^{th} reaction. The subscript "eq" on the reaction rates indicates that the rates are evaluated for equilibrium vibration. Because the finite rate of relaxation delays the population of the upper vibrational levels, a greater effective energy per collision is needed for dissociation. Hence, the equilibrium rate constants must be modified by a coupling factor. Therefore,

$$k_{f_i} = k_{f_{i_{eq}}} \prod_{j=1}^{N_s} \left(V_j\right)^{A_{ij}} \qquad [H\text{-}11]$$

where the exponent, A_{ij}, may be either zero or one to indicate whether or not the given reaction is affected by the vibration-dissociation coupling factor, V_j. By using Equation [H-10] the forward or backward reaction rate constant may be specified (input) and the other reaction rate computed from it. For example, the forward reaction rate constant can be expressed as

$$k_{f_{i_{eq}}} = A_i T^{B_i} \exp\left[-\frac{Ci}{RT^{Di}}\right] \qquad [H\text{-}12]$$

where A_i is called the frequency factor, C_i is the activation energy for the reaction, and the temperature exponents, B_i and D_i, are usually obtained from correlation of experimental reaction kinetic data. With these results and Equation [H-7], the rate of production of a given species along a given flow field streamline, s, may be more explicitly written as

$$\frac{\partial \gamma_j}{\partial s} = \frac{1}{\rho u} \sum_{i=1}^{N_R} \left[W_I \left[\left(\nu_{ij}^* - \nu_{ij} \right) k_{f_i} (\rho)^{\sum_j \nu_{ij}} \prod_{j=1}^{N_s} \left(\gamma_j \right)^{\nu_{ij}} \chi_i \right] \right.$$

$$+ D_I \left[\left\{ \frac{\left(\nu_{ij}^* - \nu_{ij} \right)}{\left(\sum_{j=1}^{N_s} \gamma_j \right)^{-1}} k_{f_i} \rho^2 \right\} \prod_{j=1}^{N_s} \left(\gamma_j \right)^{\nu_{ij}} \chi_i \right] \qquad \text{[H-13]}$$

$$\left. + Z_I \left\{ \left[\left(\nu_{ij}^* - \nu_{ij} \right) k_{f_i} \rho^2 \gamma_j \sum_{j=1}^{N_s} \left(\nu_{ij}^* - \nu_{ij} + 1 \right) \nu_{ij} \gamma_j \right] \chi_i \right\} \right]$$

In Equation [H-13], the parameters, W_I, D_I, and Z_I may be either zero or one to denote the type of reaction. For example, in the case of specific collision partners, $W_I = 1$, while $D_I = Z_I = 0$. Such a reaction would be of the type

$H_2 + H \rightleftarrows 2H + H.$

If all the collision partners are lumped together, such as in

$H_2 + M \rightleftarrows 2H + M,$

then $D_I = 1$, while $W_I = Z_I = 0$

The third term is used when some of the collision partners are lumped, while others are specified.

The parameter χ_i, appearing in Equation [H-13] is defined as

$$\chi_i = 1 - \frac{\rho^{\sum_{j=1}^{N_s} \left(\nu^*_{ij} - \nu_{ij}\right)}}{\prod_{j=1}^{N_s} \left(V_j\right)^{A_{ij} K_i}} \prod_{n=1}^{N_s} \left(\gamma_n\right)^{\nu_{ij}^* - \nu_{ij}} \qquad [H\text{-}14]$$

where K_i is the equilibrium constant for the i^{th} reaction. The significance of χ_i is that it represents the degree of nonequilibrium,

$$\chi_i = 1 - \frac{\text{reverse rate}}{\text{forward rate}}$$

and at equilibrium, χ_i is zero. Immediately behind the shock, $\chi_i = 1$; in a region of rapid recombination, χ_i may assume large negative values.

B. THE FLOW FIELD EQUATIONS

As noted earlier, the inviscid body flow field is defined as that portion of the flow bounded by the bow shockwave and the body boundary layer. The flow forward of the sonic line (Fig. H-1) is subsonic; that aft of the sonic line is supersonic. As a result, the partial differential equations governing the flow field change from elliptic to hyperbolic as the flow crosses the sonic line. Since this is the case, the analysis is best performed by using different integration techniques in the two regimes. In the subsonic regime the equations are numerically integrated using Runge-Kutta techniques; for the supersonic flow a modification of the method of characteristics is applied. These two flow regimes are discussed in this section.

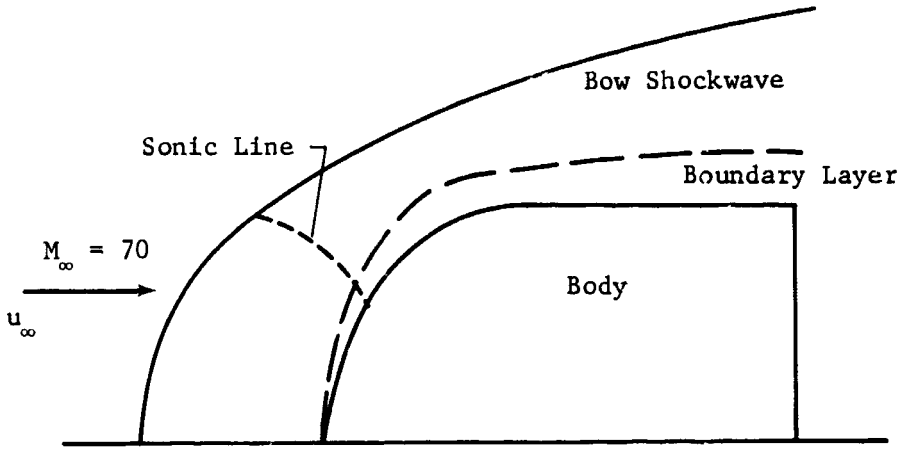


Figure H-1 Inviscid Body Flow Field

The Inviscid Subsonic Body Flow Field

The inverse method, which specifies the shock shape and calculates the body shape, was selected for this analysis primarily because, in contrast to the integral method of Belotservkovskii, the inverse method yields detailed results at field points throughout the shock layer. The differential equations governing the flow field are integrated on a coordinate system in which one set of rays is parallel to the shock and the other set of rays is normal to the shock. The thermochemical flow field properties are then calculated at each grid-point of this curvilinear, orthogonal coordinate system. Figure H-2 illustrates the coordinate system, and Figure H-3 shows the variation of temperature and density at selected grid points in the subsonic flow field.

The vector forms of the subsonic flow field conservation equations follow.

Conservation of Mass

$$\nabla \cdot (\rho \vec{u}) = 0 \qquad \text{[H-15]}$$

Conservation of Momentum

$$(\vec{u} \cdot \nabla)\vec{u} = \frac{1}{\rho} \nabla P \qquad \text{[H-16]}$$

Conservation of Energy

$$\vec{u} \cdot \nabla H = 0 \qquad \text{[H-17]}$$

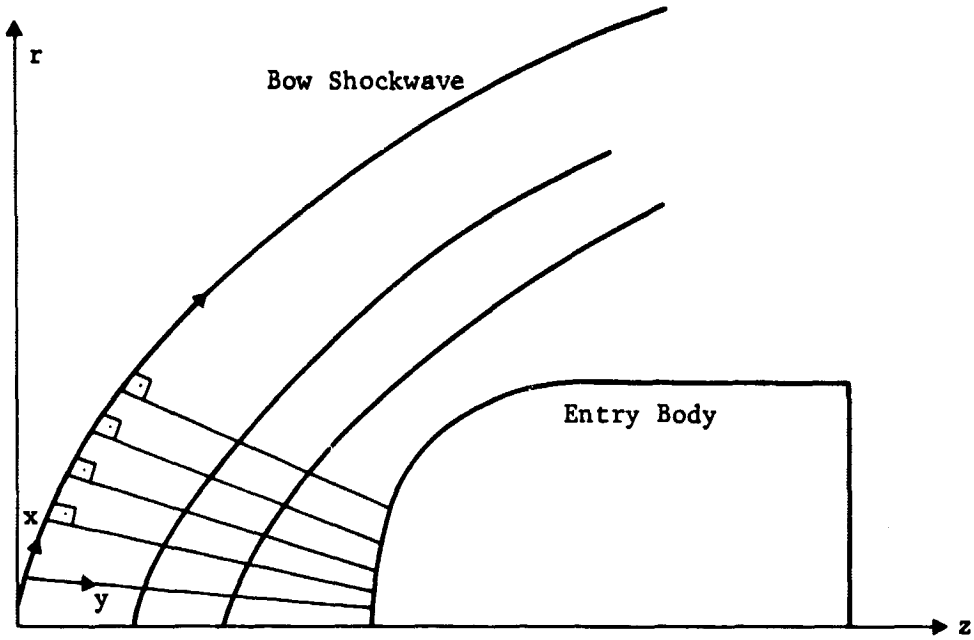


Figure H-2 Coordinate System for Integration of the Subsonic Flow Field Equations

Point	T*	ρ*
1	727.8	7.761
2	713.5	7.776
3	729.8	7.504
4	696.9	7.732

Note: $\rho^* = \rho/\rho_\infty$, $T^* = T/T_\infty$

$\rho_\infty = 4.3 \times 10^{-10}$ gm/cc, $T_\infty = 95.5°K$

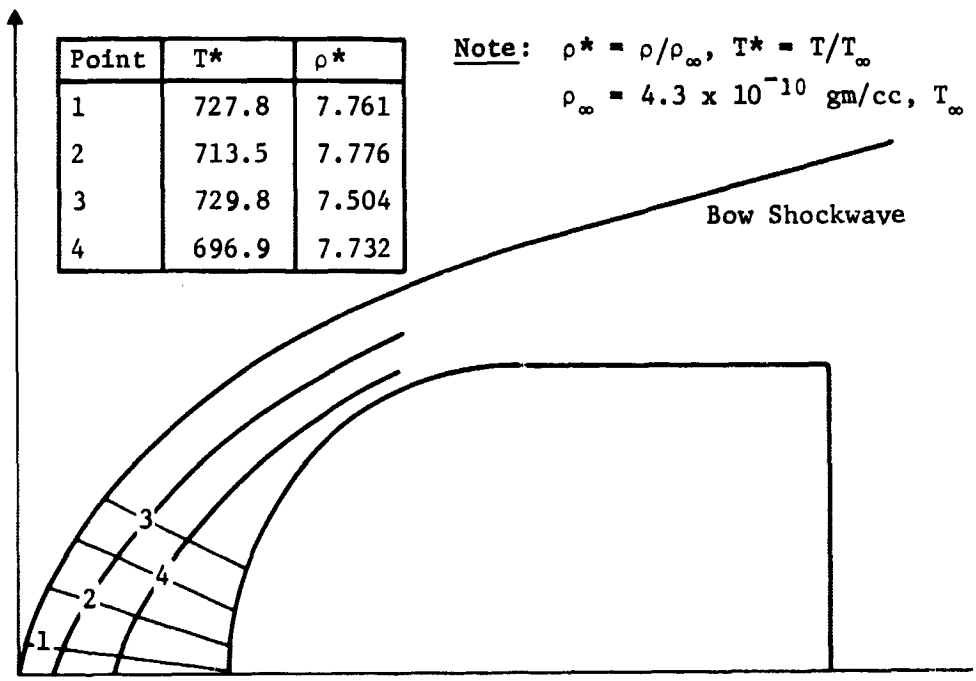


Figure H-3 Shock Layer Field Point Coordinate System with Calculated Thermo-Properties Variations

Conservation of the j^{th} Chemical Species

$$\vec{u} \cdot \left(\nabla \gamma_j\right) = \frac{1}{\rho} \sum_{i=1}^{N_R} Q_{ij} \left(T, \rho, \left\{\gamma_j\right\}, \varepsilon_j\right) \qquad [H\text{-}18]$$

Conservation of ℓ^{th} Chemical Element

$$\sum_{j=1}^{N_s} \alpha_{jk} \left(\vec{u} \cdot \nabla \gamma_j\right) = 0, \qquad k = 1, 2, \ldots, N_c \qquad [H\text{-}19]$$

Conservation of Vibrational Energy

$$\vec{u} \cdot \nabla \varepsilon_j = w_j \left(T, \varepsilon_j, \sum_{i=1}^{N_R} Q_{ij}\right) \qquad [H\text{-}20]$$

The two equations of state supplementing this system are,

$$T = \frac{\Lambda(P)(MW)}{\rho} \qquad [H\text{-}21]$$

and

$$H = \sum_{j=1}^{N_s} \left[h_j(T) + h_j^0 + \varepsilon_j\right] \gamma_j + \frac{\Lambda}{2} \vec{u} \cdot \vec{u} \qquad [H\text{-}22]$$

The equations given above are transformed to the curvilinear coordinate system depicted in Figure H-2. They are then numerically integrated, using Runge-Kutta integration techniques to give the detailed flow field solution. The details of the transformation and integration techniques are given in Reference 1 and will not be repeated here. It is worth noting, however, that convergence of the integration scheme (and location of the body-point along a ray) is determined by mass-balancing.

The dimensional mass flux into the shock between the body symmetry axis and a given X-station, M, is

$$\psi(M) = (2\pi)^{\omega} \int_0^{r_{SH}(M)} \rho_\infty \left[u_z - u_r \operatorname{cot} \sigma\right] r_{SH}^{\omega} dr \qquad [H\text{-}23]$$

where u_z, u_r are components of the velocity vector, ρ_∞ is the freestream gas density, and σ is the bow shock angle with respect to the centerline at the given r-station. The exponent, ω, is zero for two-dimensional flow, and one for axisymmetric flow. In the computational procedure, the mass flux is nondimensionalized, giving

$$\psi_{nondim}(M) = \psi_{SH}(M) \Big/ \rho_\infty u_\infty R_{SH}^{(\omega + 1)} \qquad [H\text{-}24]$$

where R_{SH} is the bow shock radius at the centerline. Therefore, at a general point on a ray

$$\psi(M) = \psi_{SH}(M) - \int_0^y (2\pi r)^{\omega} \rho u dy \qquad [H\text{-}25]$$

Inward integration is continued until $\psi(M)$ is less than some small input constant, called $\psi_{edge}(M)$. This implies that the flow has reached the body. Because all of the rays do not always reach the same distance from the shock wave before termination of the integration, an irregular (e.g. wavy) body surface may result. In such cases, iteration of the procedure with adjustments to the input shock shape becomes necessary.

2. The Inviscid Supersonic Calculation

The supersonic inviscid flow field is calculated by an adaptation of the method of characteristics. The method used has proven to be convergent within reasonable computer times.[1] The derivation of the characteristic equations is given below. A detailed discussion of the computer techniques applied to integrate these equations is given in Reference 1.

Derivation of the Characteristic Equations:

For an inviscid, compressible, reacting supersonic flow the conservation equations may be expressed as follows.

Conservation of Mass

$$\frac{u}{\rho}\frac{\partial \rho}{\partial s} = -\frac{\partial u}{\partial s} - u\left(\frac{\partial \phi}{\partial \eta} + \frac{\omega}{r}\sin\phi\right) \qquad [H\text{-}26]$$

Conservation of Momentum

$$u^2\frac{\partial \phi}{\partial s} = -\frac{1}{\rho}\frac{\partial P}{\partial \eta} \qquad [H\text{-}27]$$

$$u\frac{\partial u}{\partial s} = -\frac{1}{\rho}\frac{\partial P}{\partial s} \qquad [H\text{-}28]$$

Conservation of Energy

$$\frac{\partial h}{\partial s} = -u\frac{\partial u}{\partial s} \qquad [H\text{-}29]$$

where

ϕ = flow angle

r = the radial coordinate

η = a coordinate normal to the streamline, S, of interest

s = the streamline coordinate

$$\omega = \begin{cases} 0, & \text{for 2-dimensional flow} \\ 1, & \text{for axisymmetric flow} \end{cases}$$

The mixture static enthalpy is given by

$$h^{mix} = \sum_{j=1}^{N_s} \gamma_j \left(I_j + h_j^0 + \varepsilon_j\right)$$

$$= \sum_{j=1}^{N_s} \gamma_j h_j' + \sum_{k=1}^{N_{vib}} \gamma_{i_{N_c}+k}\,\varepsilon_k \qquad [H\text{-}30]$$

Here, h_j' denotes all of the species enthalpy except that caused by vibration, and the second term denotes the vibrational contributions to mixture enthalpy. The variation of concentration of the j^{th} chemical species along a streamline, s, as given by the two following equations:

$$u\left(\partial\gamma_j/\partial s\right) = \frac{1}{\rho}\sum_{j=1}^{N_R} Q_{ij}, \qquad j = N_c + 1, \ldots, N_s \qquad \text{[H-31]}$$

$$u\frac{\partial\epsilon_j}{\partial s} = w_j \qquad \text{[H-32]}$$

The equation of state for the gas mixture is

$$P = \rho RT\sum_{j=1}^{N_s}\gamma_j \qquad \text{[H-33]}$$

The derivation of the characteristic equations, from this system, may be started by eliminating as many derivatives as possible from Equations [H-26] through [H-32]. Consider, first, Equations [H-28], [H-29], and [H-30]. Differentiation of Equation [H-30], with respect to s, yields:

$$\frac{\partial h}{\partial s} = \sum_{j=1}^{N_s}\gamma_j\frac{\partial h_j'}{\partial s} + \sum_{j=1}^{N_s} h_j'\frac{\partial\gamma_j}{\partial s} + \sum_{k=1}^{N_{vib}}\epsilon_k\frac{\partial\gamma_{N_c+k}}{\partial s} + \sum_k \gamma_{N_c+k}\frac{\partial\epsilon_k}{\partial s}$$

$$= \sum_j \gamma_j\frac{\partial h_j'}{\partial T}\frac{\partial T}{\partial s} + \sum_j h_j'\frac{\partial\gamma_j}{\partial s} + \sum_{k=1}^{N_{vib}}\gamma_{N_c+k}\frac{\partial\epsilon_k}{\partial s} + \sum_k \epsilon_k\frac{\partial\gamma_{N_c+k}}{\partial s} \qquad \text{[H-34]}$$

Noting that

$$\sum_{j=1}^{N_s} \gamma_j \frac{\partial h_j}{\partial T} \frac{\partial T}{\partial s} = C_p \frac{\partial T}{\partial s}$$

gives the result that

$$\frac{\partial h}{\partial s} = C_p \frac{\partial T}{\partial s} + \sum_j h_j' \frac{\partial \gamma_j}{\partial s} + \sum_k \left(\gamma_{N_c+k} \frac{\partial \epsilon_k}{\partial s} + \epsilon_k \frac{\partial \gamma_{N_c+k}}{\partial s} \right) \qquad [H-35]$$

Substitution of Equations [H-28] and [H-29] into Equation [H-30] yields

$$\frac{1}{\rho} \frac{\partial P}{\partial s} = \frac{\partial h}{\partial s} = C_p \frac{\partial T}{\partial s} + \sum_j h_j' \frac{\partial \gamma_j}{\partial s} + \sum_{k=1}^{N_{vib}} \gamma_{N_c+k} \frac{\partial \epsilon_k}{\partial s} \qquad [H-36]$$

Now from the equation of state, e.g. Equation [H-33], one obtains

$$\frac{\partial \rho}{\partial s} = \left(\frac{1}{RT \sum_{j=1}^{N_s} \gamma_j} \right) \frac{\partial P}{\partial s} - \frac{\rho}{T} \frac{\partial T}{\partial s} - \left(\frac{\rho}{\sum_{j=1}^{N_s} \gamma_j} \right) \frac{\partial \gamma_j}{\partial s} \qquad [H-37]$$

Now if Equation [H-26] and [H-28] are combined, the result is,

$$\frac{\partial \rho}{\partial s} = \frac{1}{u^2} \frac{\partial P}{\partial s} - \rho \left(\frac{\partial \phi}{\partial \eta} + \frac{\omega \sin \phi}{r} \right) \qquad [H-38]$$

If Equation [H-37] is substituted into Equation [H-38], the result is

$$\left(\frac{1}{RT \sum_{j=1}^{N_s} \gamma_j} \right) \frac{\partial P}{\partial s} - \frac{\rho}{T} \frac{\partial T}{\partial s} - \left(\frac{\rho}{\sum_{j=1}^{N_s} \gamma_j} \right) \frac{\partial \gamma_j}{\partial s} = \frac{1}{u^2} \frac{\partial P}{\partial s} - \rho \left(\frac{\partial \phi}{\partial \eta} + \frac{\omega \sin \phi}{r} \right) \qquad [H-39]$$

If Equation [H-36] is solved for $\frac{\partial T}{\partial s}$, and the resulting expression is substituted into Equation [H-39], the result is,

$$\frac{1}{\rho}\left(\frac{1}{u^2}+\frac{1}{C_p T}-\frac{1}{RT\sum_{j=1}^{N_s}\gamma_j}\right)\frac{\partial P}{\partial s}-\frac{\partial \phi}{\partial \eta}=\frac{\omega \sin\phi}{r}+\frac{1}{C_p T}\sum_{j=1}^{N_s}h_j'\frac{\partial \gamma_j}{\partial s}$$
$$+\frac{1}{C_p T}\sum_{k}^{N_s}\frac{\partial \gamma_{N_c+k}}{\partial s}-\frac{\sum_{j=1}^{N_s}\frac{\partial \gamma_j}{\partial s}}{\sum_{j=1}^{N_s}\gamma_j} \qquad [H\text{-}40]$$

Note that, of the original system of equations, all except Equation [H-27] have been used in the derivation of Equation [H-40]. Therefore, the original set of equations governing the inviscid supersonic flow field has been reduced to a set of two equations, involving four derivatives, $\frac{\partial \phi}{\partial s}$, $\frac{\partial P}{\partial \eta}$, $\frac{\partial P}{\partial s}$, and $\frac{\partial \phi}{\partial \eta}$.

The new subsystem Equations [H-27] and [H-40] must be supplemented with two additional equations, to solve for the four unknowns just given. The two supplementary equations selected by Curtis and Strom[1] are

$$\frac{\partial \phi}{\partial \eta}\,d\eta+\frac{\partial \phi}{\partial s}\,ds=d\phi \qquad [H\text{-}41]$$

$$\frac{\partial P}{\partial \eta}\,d\eta+\frac{\partial P}{\partial s}\,ds=dP \qquad [H\text{-}42]$$

Since the characteristic curves are defined as the loci of indeterminate flow derivatives, solving the set composed of Equations [H-27], [H-40], [H-41], and [H-42], and locating the regions of indeterminacy gives the characteristic lines of the flow field.

This procedure can be illustrated by grouping the four equations together and solving for the pressure gradient. This will yield explicit expressions for the characteristic network in the flow field. Therefore, application of Cramer's Rule to this set of equations yields the following expression for the pressure gradient:

$$\frac{\partial P}{\partial s} = \frac{\begin{vmatrix} B^1 & 0 & 0 & -1 \\ 0 & 1/\rho & u^2 & 0 \\ dP & d\eta & 0 & 0 \\ d\phi & 0 & ds & d\eta \end{vmatrix}}{\begin{vmatrix} -A^1 & 0 & 0 & -1 \\ 0 & 1/\rho & u^2 & 0 \\ ds & d\eta & 0 & 0 \\ 0 & 0 & ds & d\eta \end{vmatrix}} \qquad [H-43]$$

Where A^1 is the coefficient of $\frac{\partial P}{\partial s}$ in Equation [H-40], and B^1 is the righthand side of Equation [H-40].

If $\frac{\partial P}{\partial s}$ is to be indeterminant, then the numerator and denominator must vanish separately. From the vanishing of the denominator, the following relation results:

$$\frac{\partial \eta}{\partial s} = \pm \sqrt{\frac{1}{\rho A^1 u^2}} = \tan\beta \qquad [H-44]$$

Which gives two differential equations for two sets of characteristic curves. Along these curves, the numerator must also vanish, yielding,

$$\frac{1}{\rho u^2 \sqrt{\rho A^1 u^2}}\, dP \pm d\phi = -\frac{B^1 ds}{\sqrt{\rho A^1 u^2}} \qquad [H-45]$$

The compatibility equation may be obtained by using the characteristic angle, β, and a length element, $d\zeta$, defined as

$$d\zeta_{\pm} \equiv \frac{ds}{\cos\beta} \qquad [H-46]$$

where the $\pm$ notation indicates the direction of the characteristic line.

The resultant compatibility equation is

$$\frac{\cot\beta}{\rho u^2}\, dP \pm d\phi = -\left(\frac{\omega}{r}\sin\phi + \tilde{F}\right)\sin\beta\, d\zeta_{\pm} \qquad [H\text{-}47]$$

in which all nonequilibrium effects are expressed in the functional

$$\tilde{F} = \frac{1}{C_p T}\left[\sum_{j=1}^{N_s} h_j \frac{\partial \gamma_j}{\partial s} + \sum_{K=N_c+k}^{N_{vib}} \gamma_{N_c+k} \frac{\partial \varepsilon_k}{\partial s}\right] - \left(\frac{\sum_j \frac{\partial \gamma_j}{\partial s}}{\sum_j \gamma_j}\right) \qquad [H\text{-}48]$$

Along the characteristic curves the partial differential equations reduce to ordinary differential equations.

The compatibility equation and the characteristics equations are normalized using the same reference quantities as in the subsonic flow field. These are R_{SH}, ρ_∞, u_∞, $\rho_\infty u_\infty^2$, RT_∞, and $RT_\infty/(MW)_\infty$.

The details of the normalization and computational procedures are given in Reference 1.

Reference 1:

J. T. Curtis and C. R. Strom: *Computations of the Nonequilibrium Flow of a Viscous, Radiating Fluid About a Blunt Axisymmetric Body.* AFFDL TR-67-40, Volume 1, June 1967.

APPENDIX I

MULTILAYER INSULATION CONDUCTIVITY EVALUATION

C. Webb

February 1, 1972

To evaluate insulation performance accurately, two applicable data sources on multilayer insulation were obtained. The first source represented laboratory guarded hot plate test data (Ref 1), the second source represented thermal conductivity test data from an actual hardware mockup where fiberglass standoffs penetrated the insulation blanket and seams and joints were present (Ref 2). Figure I-1 presents a comparison between these two sets of data. In addition, an analytical curve fit is shown for each set where the expression representing the thermal conductivity considered both the linear conduction and the radiation associated with multilayer insulation. The expression, therefore, includes the influence of the mean insulation temperature and, in addition, the nonlinear influence of the actual boundary temperatures. The expression used for the multilayer insulation follows:

$$k = aT_M + b\left(T_H^2 + T_C^2\right)\left(T_H + T_C\right) \qquad [I-1]$$

where,

k = effective thermal conductivity

a & b = influence coefficients

T_M = insulation mean temperature

T_H = hot boundary temperature

T_C = cold boundary temperature

and

$$Q_{leak} = \frac{kA}{t}\left(T_H - T_C\right) \qquad [I-2]$$

where

Q_{leak} = Blanket heat leak

A = insulation surface area

t = insulation thickness.

The importance of this expression is that it more precisely determines the thermal conductivity as a function of boundary temperature and thus insulation thickness variations.

For the turbopause mission thermal analyses, the Skylab conductivity data was selected to determine the baseline influence coefficients of Equation [I-1] and thus the multilayer insulation performance.

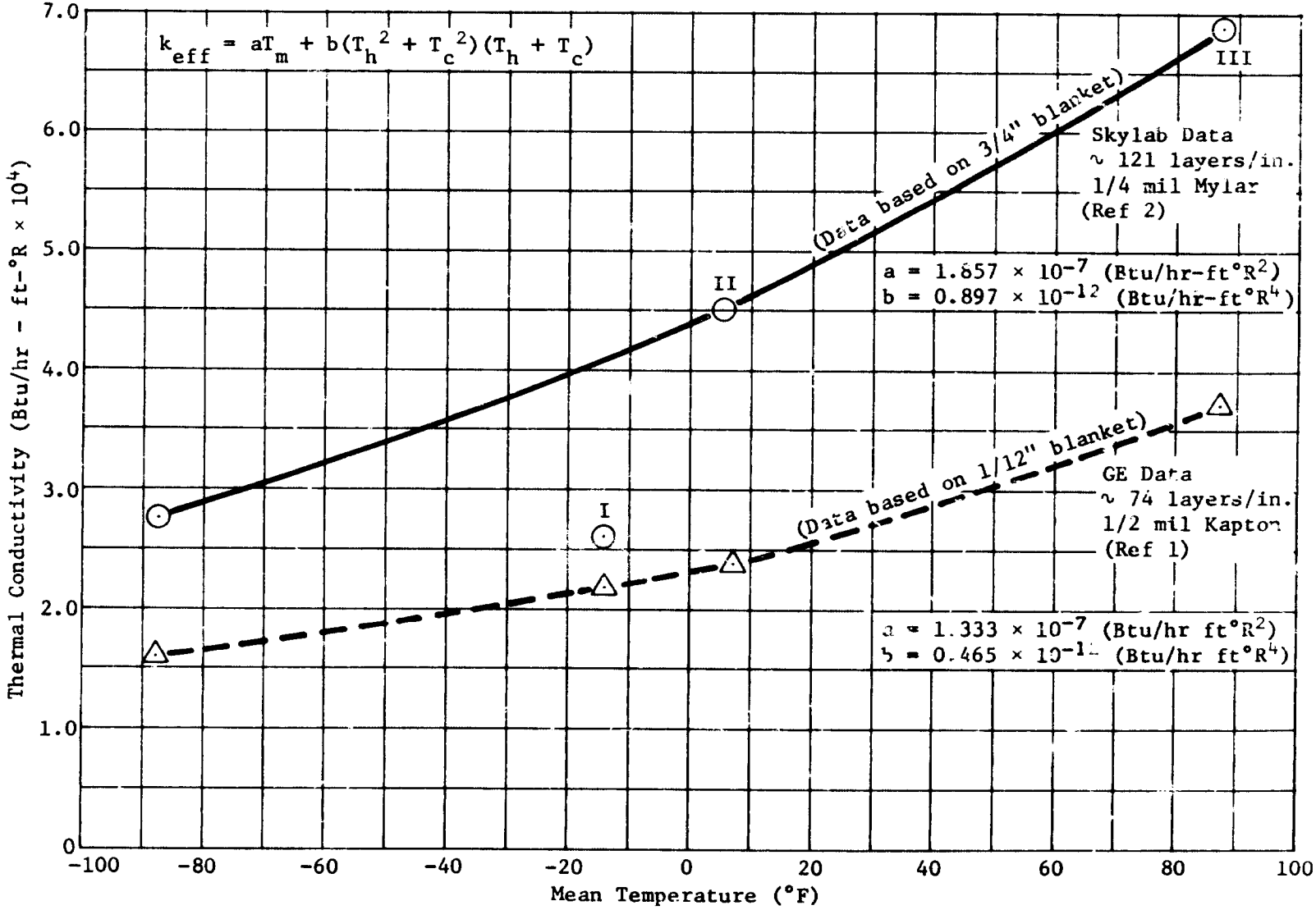


Figure I-1 Multilayer Insulation Thermal Conductivity

REFERENCES:

1. E. Fried and G. Karp, et al.: - *Measurement of Thermal Conductance of Multilayer and Other Insulation Materials.* Final Report Contract NAS9-3685, General Electric Co., Valley Forge Space Technology Center, Philadelphia, Pa, 29 September 1967.

2. D.K. One: - *Technical Summary Report MDA Thermal Component Wall Test,* Skylab Program Payload Integration Contract NAS8-24000, Martin Marietta Corporation, Denver, Colo.

APPENDIX J

THERMAL SENSITIVITY ANALYSIS

C. Webb



February 1, 1972

Perhaps the biggest uncertainty in determining the amount of internal heat required for thermal control was the thermal conductivity of the multilayer insulation blanket. Since the methods of installation and fabrication can have considerable effect on the efficiency of the insulation, a sensitivity analysis was conducted to determine to what extent lack of knowledge of the actual blanket conductivity could affect the heater power requirement. These results are presented in Figure J-1. It is expected that effective insulation conductivity will fall somewhere between 0.0002 and 0.002 W/m - °K. The response of heater power to this order of magnitude variation is approximately a factor of 2 (from 7 to 16 watts). This means that the final decision on the number of radioisotope heaters required for the probe should be made on the basis of a thermal vacuum test. This test would be relatively simple and could be performed on the actual flight article, thus precluding the expense of fabricating a thermal test prototype and establishing maximum confidence in thermal performance. Additional uncertainties in the thermal analysis were the optical properties of the beryllium heat shield, i.e., solar absorptivity and emittance. Since parts of the shield will be plated with platinum, a sample platinum-plated beryllium chip was prepared and laboratory optical property measurements performed. The platinum plating was accomplished by a thermally decomposable paint which, after heat treatment, leaves a platinum coating. A laboratory sample of cross rolled beryllium sheet was supplied and prepared by Englehard Minerals and Chemicals, Newark, New Jersey. Emissivity measurements performed by Martin Marietta indicated a value of $\varepsilon = 0.25$ for platinum-coated beryllium. These measured values are not expected to be the definitive answer for probe exterior emissivity. Considerable differences can occur, depending on the degree of polish and plating characteristics.

Analytical results showing the influence of the probe shell optical properties on the internal heater power requirement are presented in Figure J-2. These results show that the heater power is not particularly sensitive to variations in shell emissivity for values 0.20 or greater. Lower emissivity values, however, could save significant heater power but coincidently enlarge the uncertainty associated with the design due to the extreme sensitivity of heater power to variations in the probe shell emissivity in this range. For this reason, it is recommended that some effort be made, primarily through control of surface finish (polish) to ensure that the probe shell actually has an emissivity of 0.2 or greater.

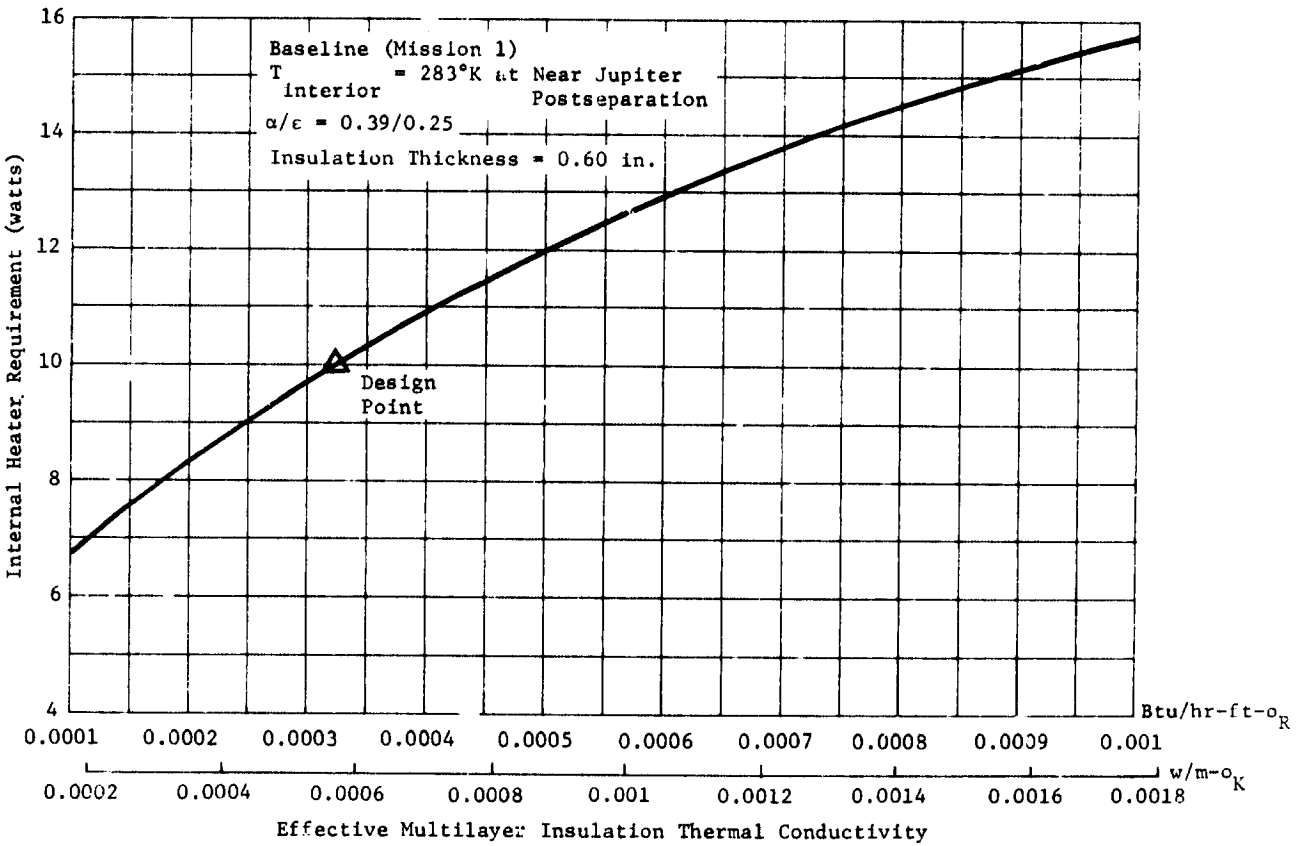


Figure J-1 Sensitivity of Heater Power to Multilayer Insulation Performance.

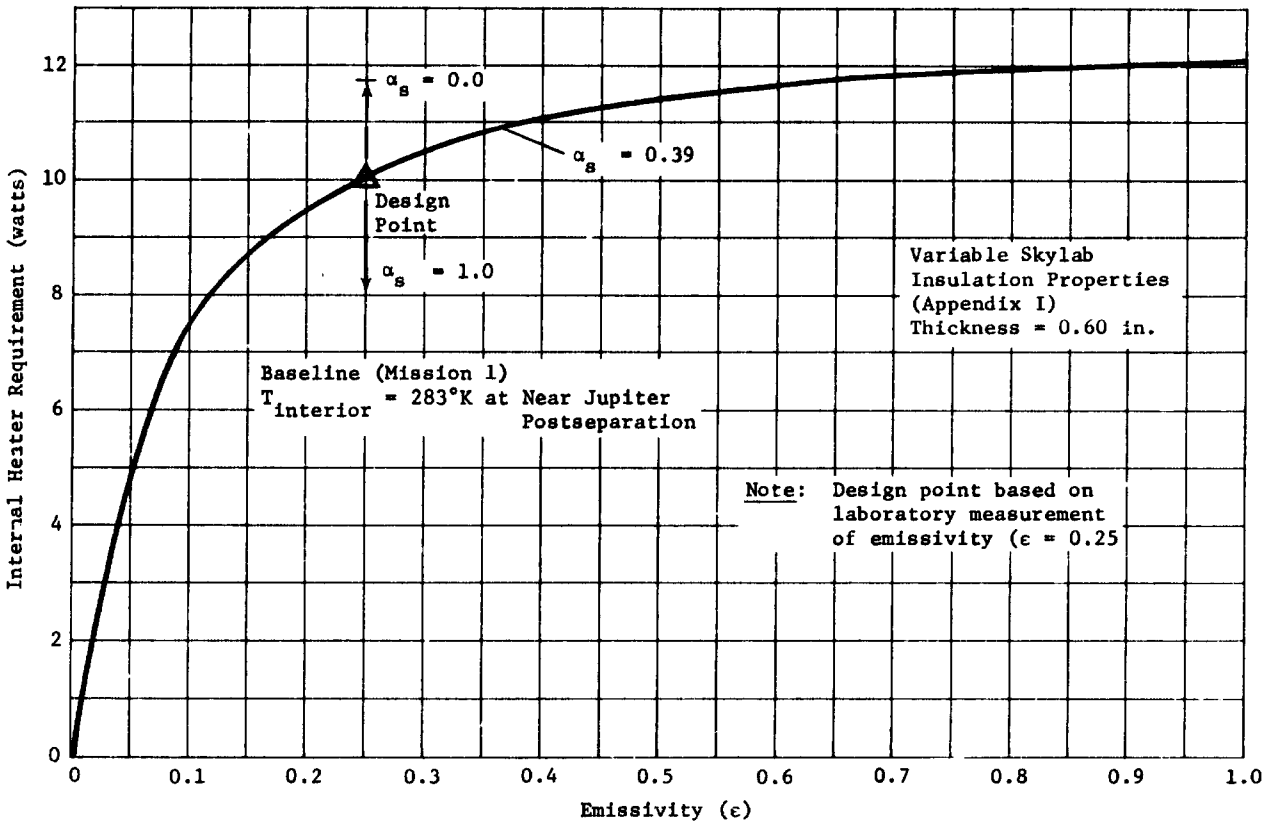


Figure 2. Sensitivity of Heater Power to Probe Shell Emissivity.

APPENDIX K

GROSS MISSION ANALYSIS FOR EARTH - JUPITER MISSIONS AND A JUPITER PROBE FOR 1976-1983

L. Anderson
D. Vogt

September 28, 1971

A parametric analysis has been completed to aid in the selection of Earth Launch Date (LD), Jupiter Arrival Date (AD) and inertial flight path angle of probe at entry (γ_E) for the 1976, 1977, 1978, 1979, 1980, 1981-1982, and 1983 launch windows. This analysis is an addendum to the data presented in Ref 1.

The following flight parameters were analyzed over the complete range of LD (1976 through 1983), AD and γ_E (7.5 to 67.5 deg):

Launch energy, C3 $(km/sec)^2$

Equatorial declination of departure $\vec{v}_{HP}$, DLA (deg)

Sun-Earth-vehicle angle at Jupiter arrival, SEV (deg)

Navigation angle at Jupiter arrival, ZAE (deg)

Sun-Jupiter - $\vec{v}_{HP}$ angle at Jupiter arrival, ZAP (deg)

Probe illumination angle at entry, λ (deg)

Probe-Earth communication angle at entry, ψ (deg)

Minimum entry angle consistent with 20° mask angle, γ_{min} (deg)

These parameters are discussed in detail in Ref 1 and 2.

The constraints on these parameters follow.

Soft Constraints	Caused by
C3 < 130	Launch vehicle capability (T3D-Centaur)
$\|DLA\|$ > 2	Navigation for first midcourse correction
$\|DLA\|$ < 36	Range safety
ZAE ≠ 90	Doppler navigation approaching Jupiter
ZAP < 150	Minimum probe γ_E requirements
λ < 70	Minimum probe lighting condition
$\|\psi\|$ < 20	Favorable probe - Spacecraft-Earth communication geometry

Hard Constraints	Caused by
C3 $\leq$ 170	Launch vehicle capability (T3D-7 Centaur)
$\|DLA\| \leq 40$	Range safety
$\|SEV\| > 15$	Sun obstruction at Jupiter arrival

A. MISSION ANALYSIS

For all launch windows, there is a tradeoff that must be made between probe γ_E and launch window duration. If science, aeroheating, or communications require that the probe enter with lower γ_E, such as less than 30 degrees, and still maintain lighting conditions, then the window of allowable ADs is restricted to later dates, reducing the available launch window as illustrated in Figure K-1. This relationship between minimum possible γ_E, AD, and launch window is illustrated in the C3 plots (Figure K-2). Reference 3 states that the minimum launch window requirement for the Titan IIID/5 segment vehicle is 20 days, and the minimum for the Titan IIID/7 segment vehicle is 30 days. These requirements are indicated on Figure K-1.

There is also a tradeoff to be made between γ_E, and time of flight, since smaller probe γ_E angles require later Jupiter ADs. This tradeoff is also approximately illustrated on Figure K-1. For all launch windows, the time of flight can vary from about 450 to 1250 days.

The only other AD limitation common to all AD windows is the sun obstruction constraint. The sun obstruction occurs for two 40-day intervals during the 750-day AD window, but is easily avoided by small changes in Earth-Jupiter targeting.

The only significant differences in the seven LD windows considered are the presence of range safety constraints in 1977, 1978, and 1979 and a midcourse navigation constraint in 1981-1982. Assuming that all of these constraints are hard constraints, the launch windows fall into the order of most favorable to least favorable as follows:

LD Window	Minimum γ_E Possible*	Comments
1976	0	No launch constraints
1983	0	No launch constraints
1980	0	No launch constraints, narrower LD window
1977	16.5	Partly constrained by range safety
1979	20	Partly constrained by range safety
1978	26.5	Partly constrained by range safety
1981-82	0	Completely constrained by midcourse navigation

*Approximate, assuming a 20-day launch window requirement and a launch vehicle capability of C3 not greater than 130.

B. PRESENTATION OF DATA

Figures K-2 through K-15 present the new data generated for this analysis. This form of data presentation is made possible by recent modifications to the computer programs GEØM1 (written by A. Barger) and CØNTØUR (written by F. Peterson). Additional parametric presentations of this form can be generated as needed.

The C3 contour graphs are similar to those presented in Ref 1, with the following exceptions. The basic data and hardcopy plots are generated by a single computer run instead of generating rough data first and then having graphs hand plotted. The graphs include the parameters ZAE and ZAP which have not been previously plotted.

The λ, ψ plots are similar to data presented in Ref 1, but cover other LD windows in addition to 1978. Again the plots are machine-generated instead of hand-drawn. The data on each λ, ψ plot corresponds to a single launch date at the center of the LD window as noted in the X-axis label. Two λ, ψ plots, Figures K-5 and K-6, were generated for the 1977 window, corresponding to two different launch dates. A 10-day change in LD produced only small changes (less than one degree) in the λ and ψ contours.

C. CONCLUSIONS

Considering the 1978, 1979, and 1980 launch windows, the 1978 is least attractive for flight path angles less than 30 degrees. This is due to the range safety constraint that eliminates a significant portion of the launch window. For example, if the probe is targeted to a γ_E of 20 degrees, then the C3 requirements are 150 $(km/sec)^2$ for a 20-day launch window and 200 $(km/sec)^2$ for a 30-day launch window. Either 1979 or 1980 presents a better alternative, if the probe must enter at low γ_E.

D. REFERENCES

1. *Jupiter Launch Date/Arrival Date Parameters.* Martin Marietta 0443-71-OP-100, 18 August 1971.

2. *Deterministic Study of Probe Deflection Maneuver.* Martin Marietta 0443-71-OP-101, 17 September 1971.

3. *Titan III/Centaur Family Launch Vehicles for a Jupiter Entry Mission Study.* JPL Section Document 131-09, 14 January 1970.

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3. *Titan III/Centaur Family Launch Vehicles for a Jupiter Entry Mission Study.* JPL Section Document 131-09, 14 January 1970.

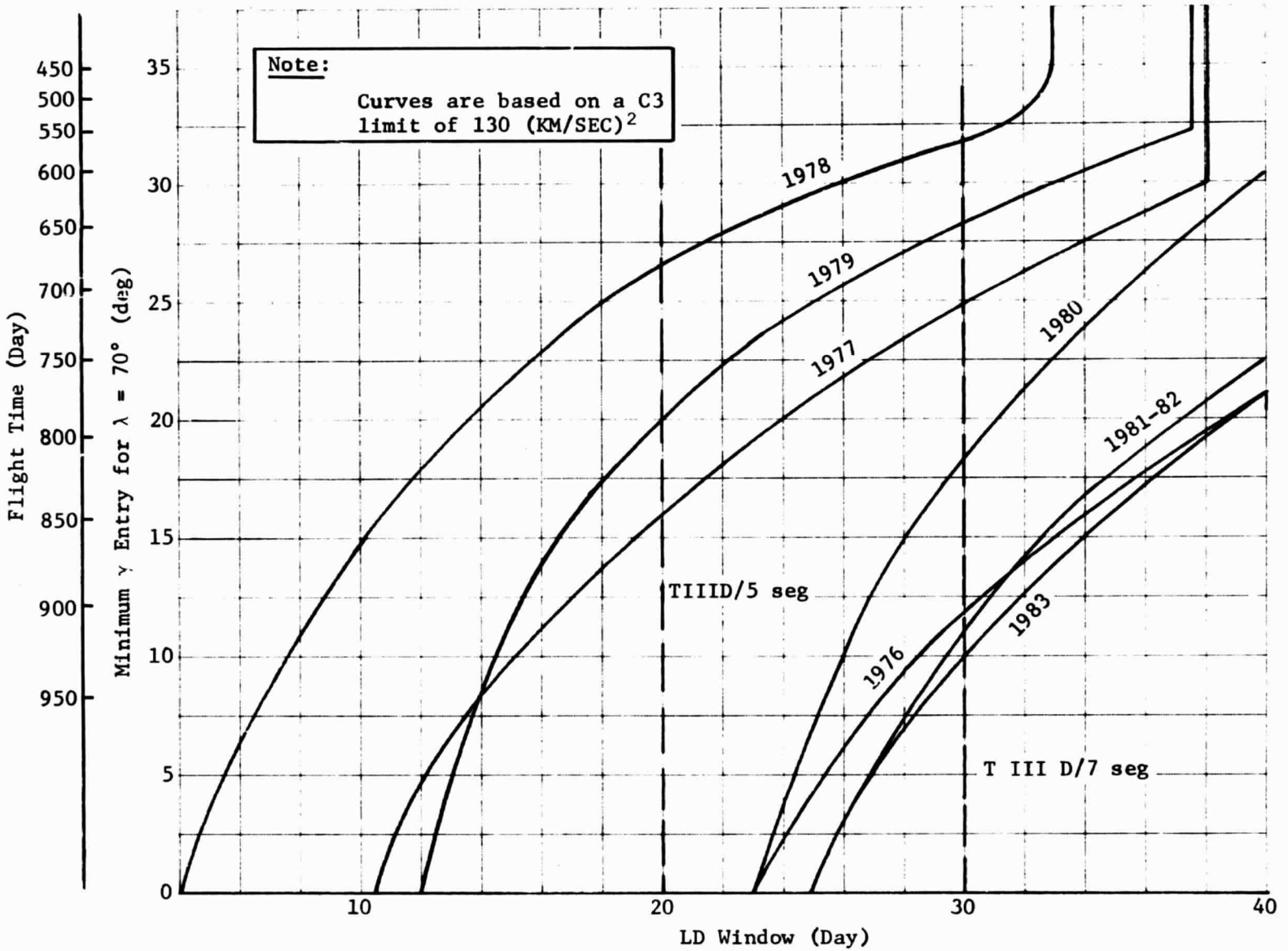


Fig. K-1 Entry Angle, Launch Window and Flight Time Tradeoff, 1976 to 1983

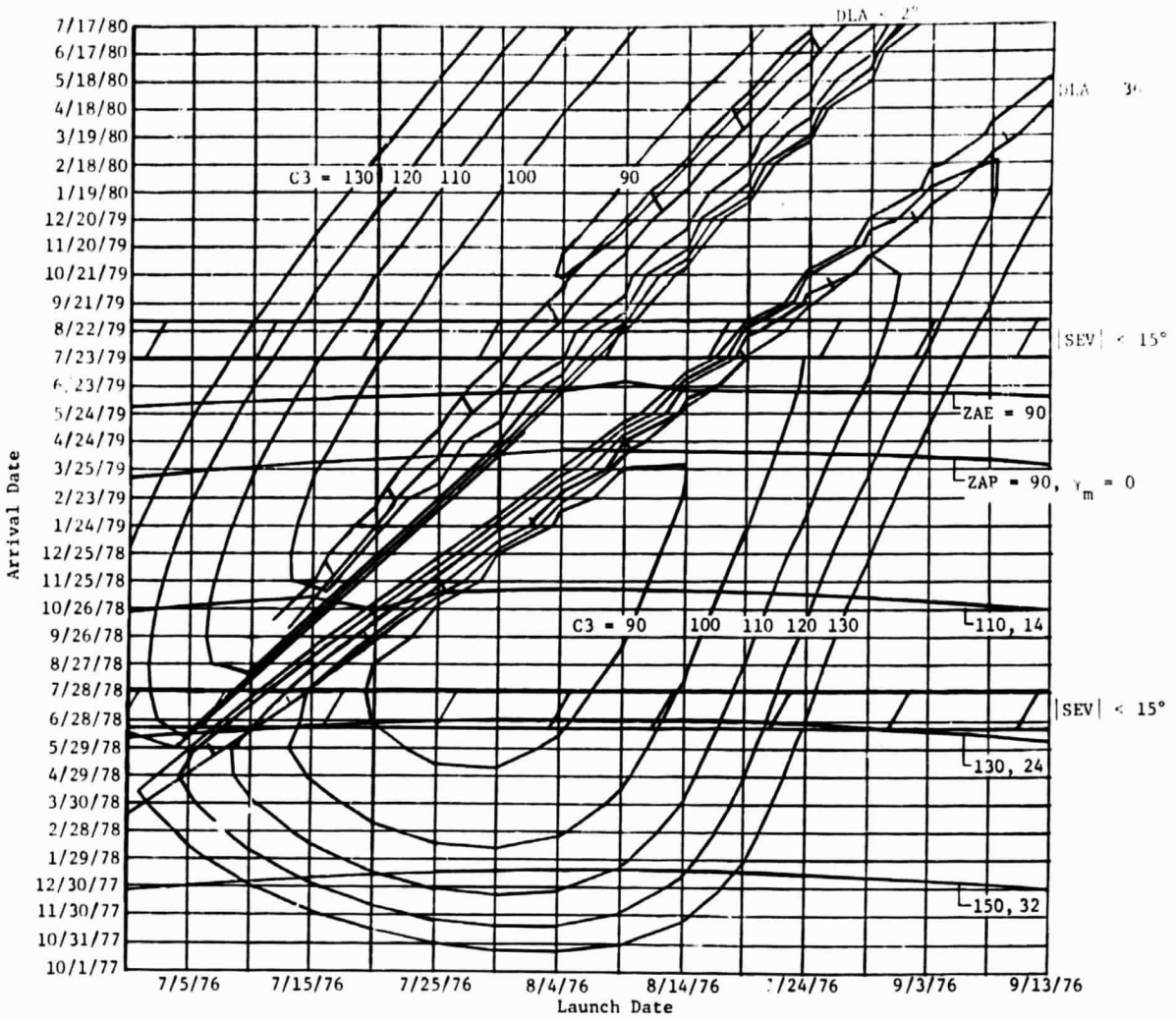


Fig. K-2 Jupiter Turbopause Probe Study
1976 Launch, Type I and II
(TF At X,Y=(0,0) is 458 Days)

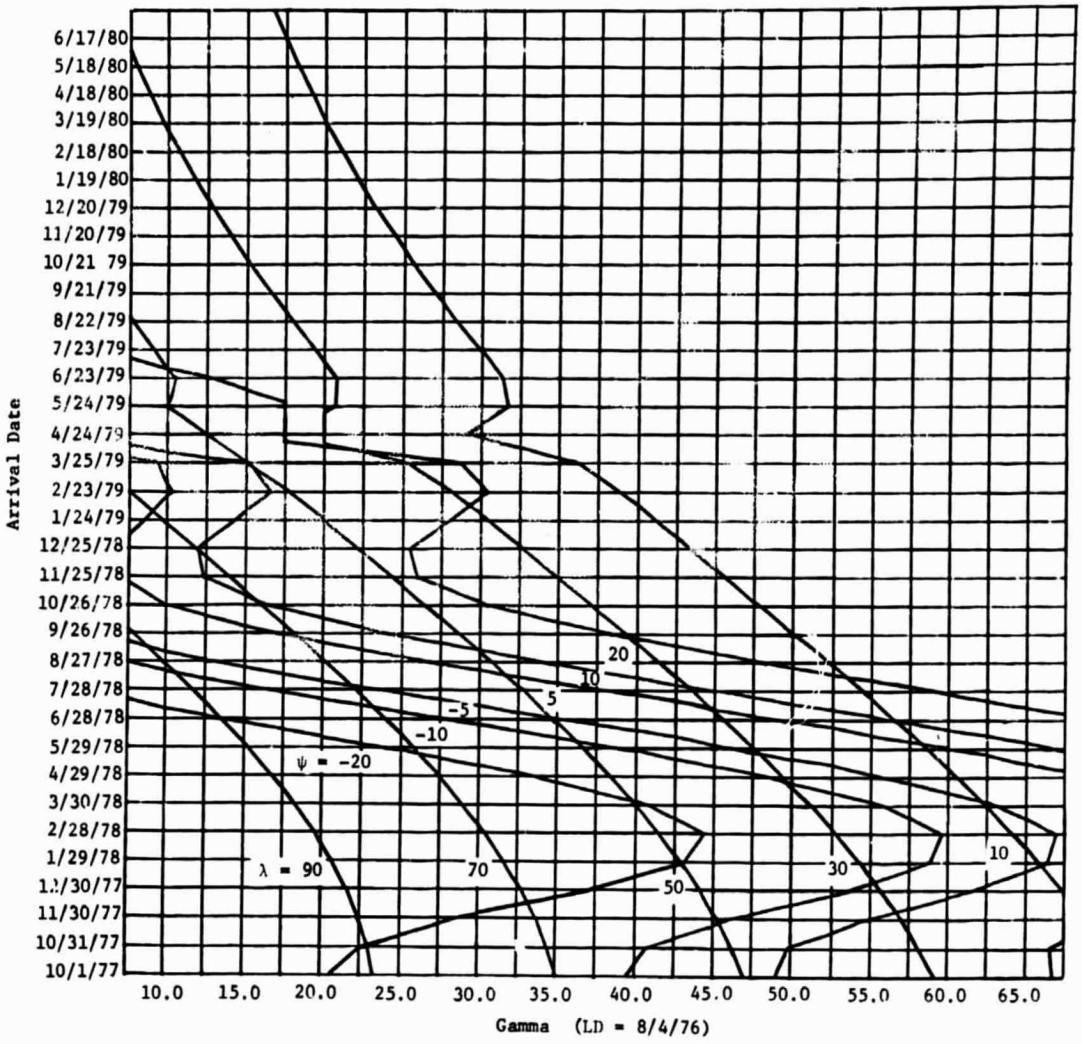


Fig. K-3 Jupiter Turbopause Probe Study 1976 Launch, Type I and II (TF At X,Y=(0,0) Is 458 Days)

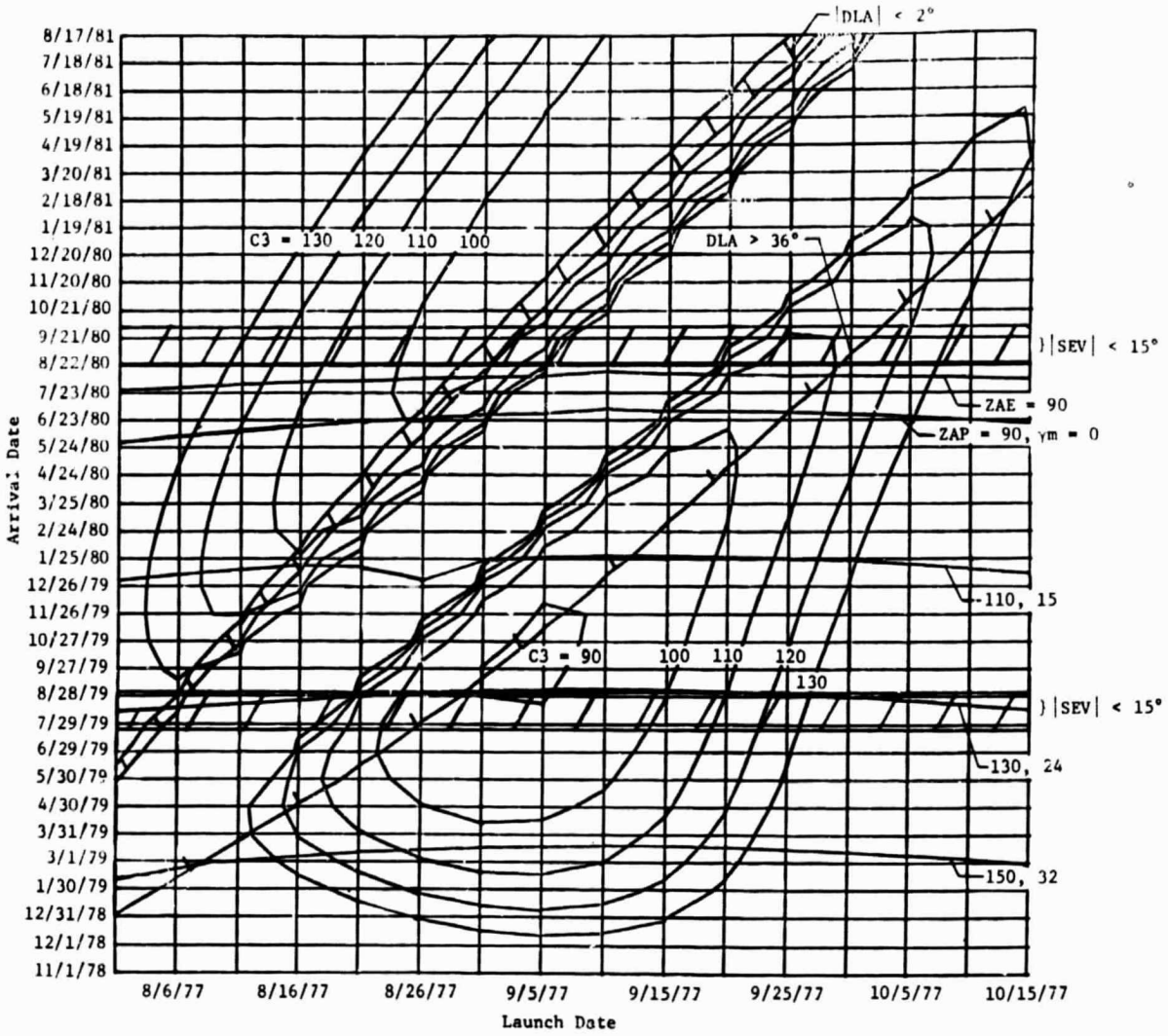


Fig. K-4 Jupiter Turbopause Probe Study 1977 Launch, Type I and II (TF at X,Y=(0,0) is 457 Days)

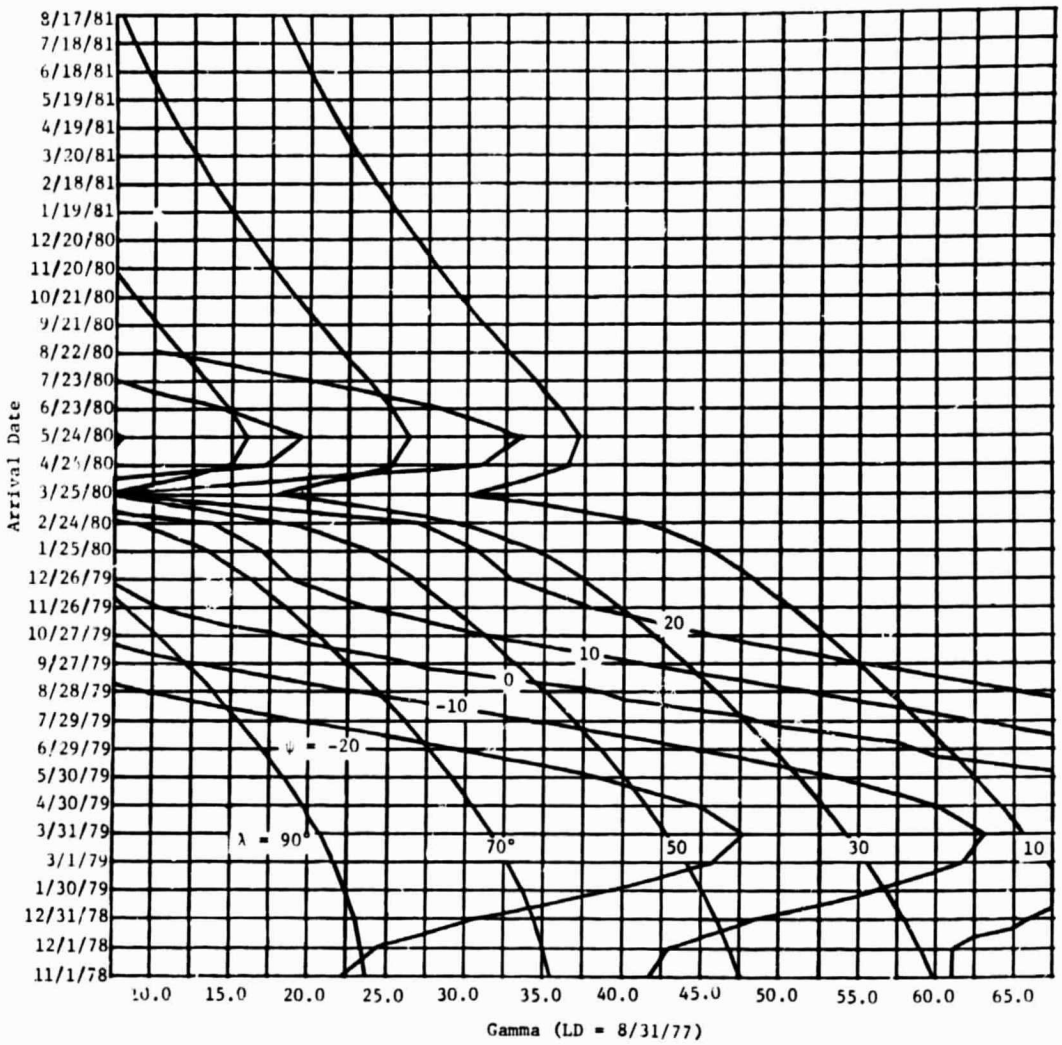


Fig. K-5 Jupiter Turbopause Probe Study 1977 Launch, Type I and II

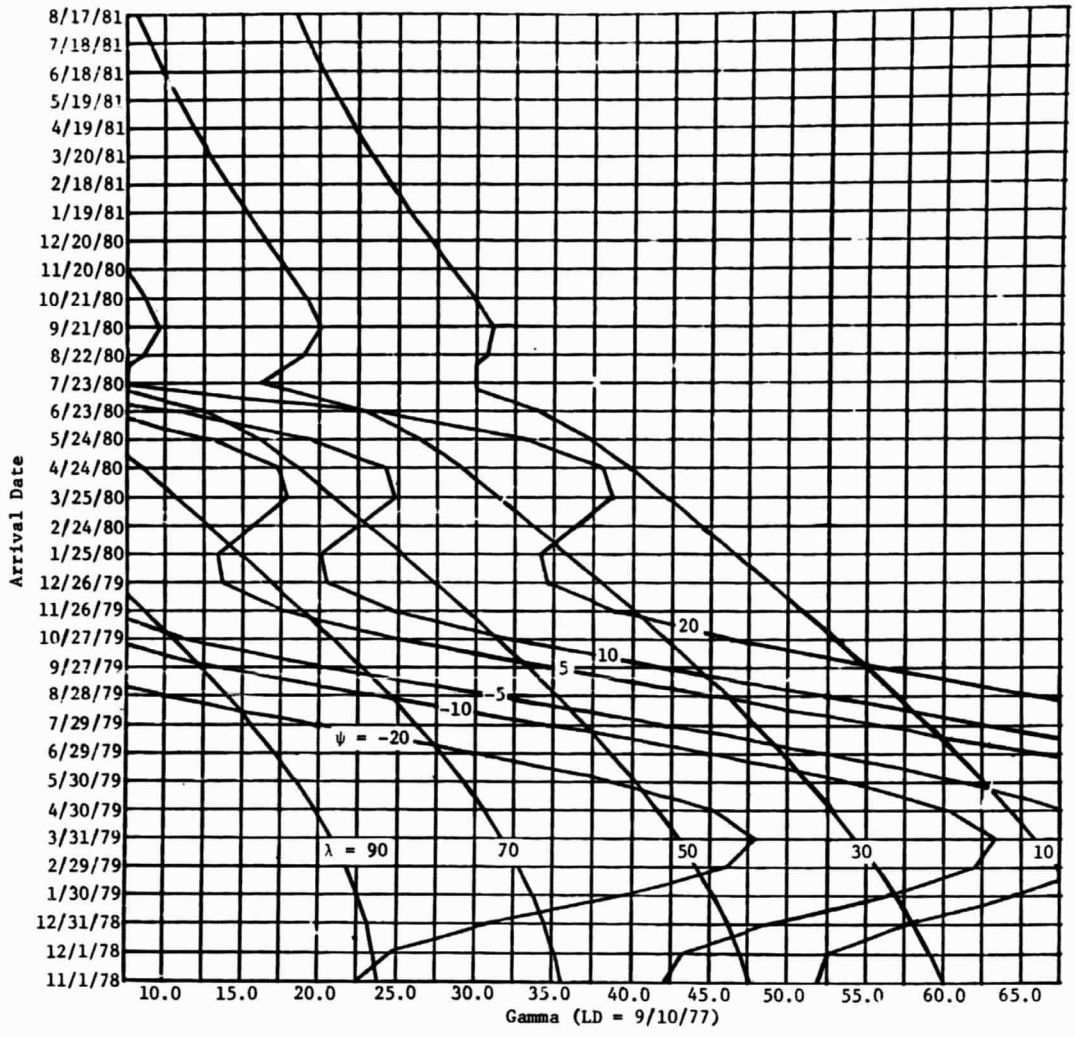


Fig. K-6 Jupiter Turbopause Probe Study
1977 Launch, Type I and II
(TF at X,Y = (0,0) is 457 Days)

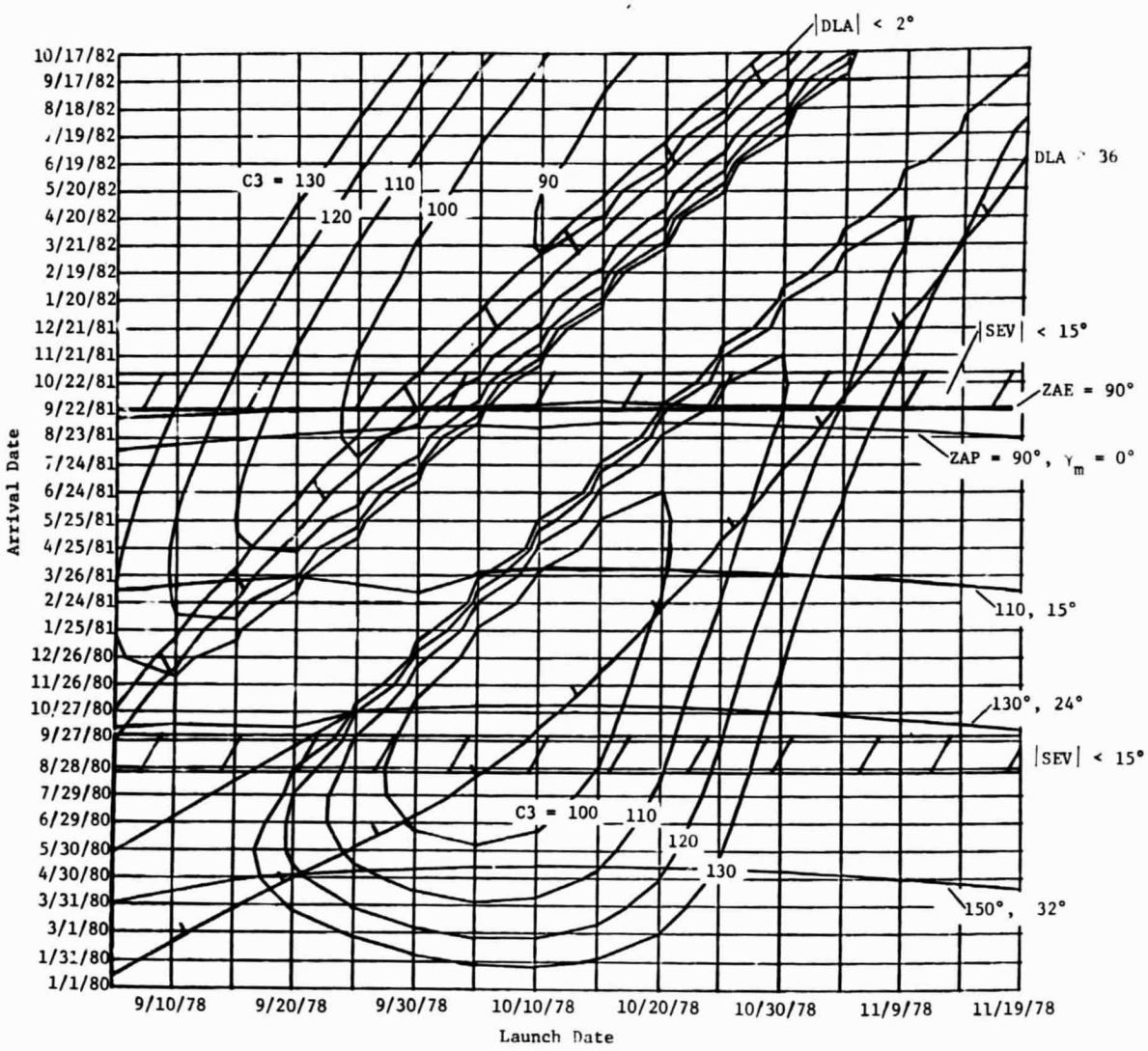


Fig. K-7 Jupiter Turbopause Probe Study
1978 Launch, Type I and II
(TF at X, Y = (0,0) is 483 Days)

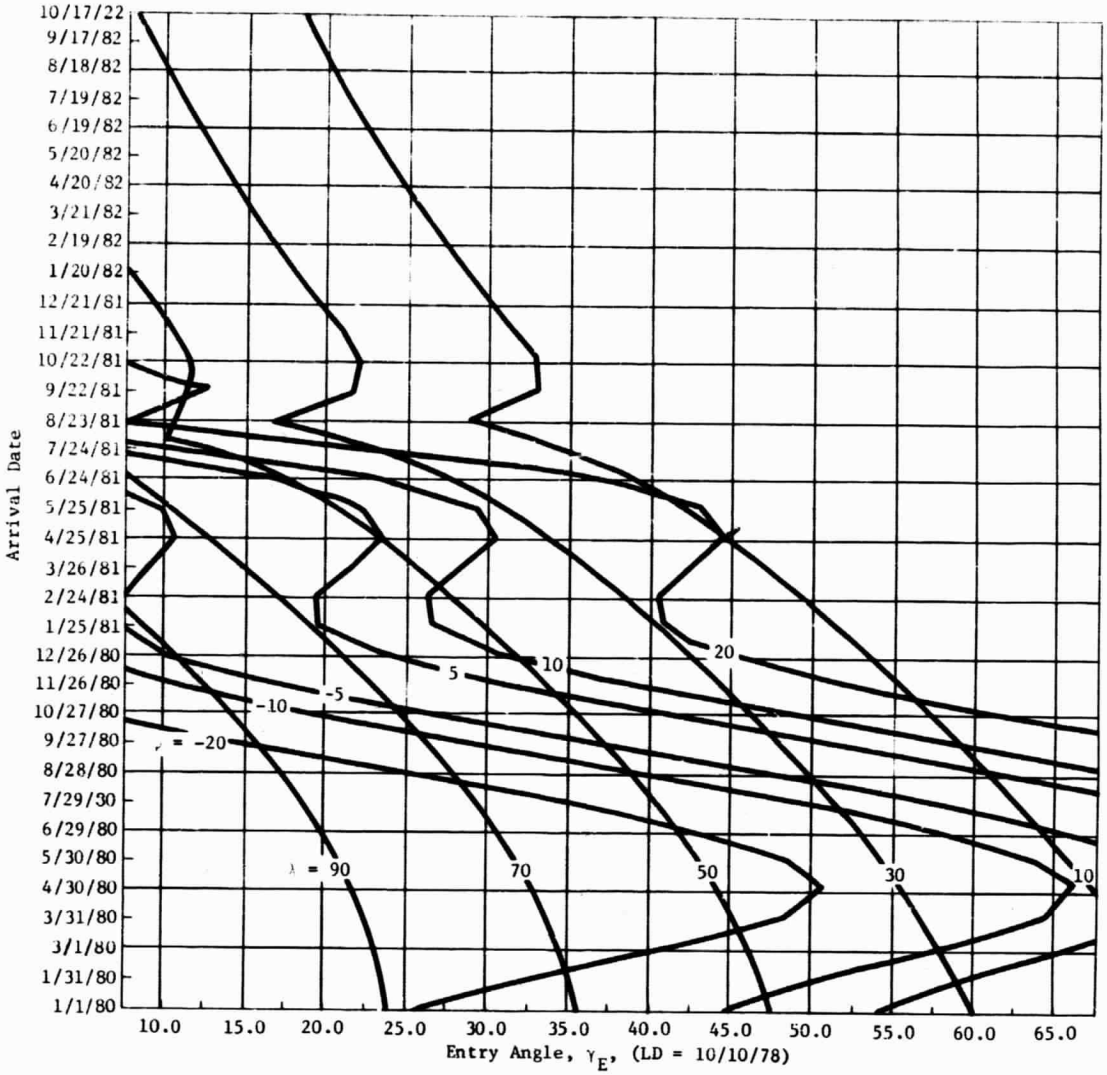


Fig. K-8 Jupiter Turbopause Probe Study
1878 Launch, Type I and II
(TF at X, Y = (0.0) is 483 days)

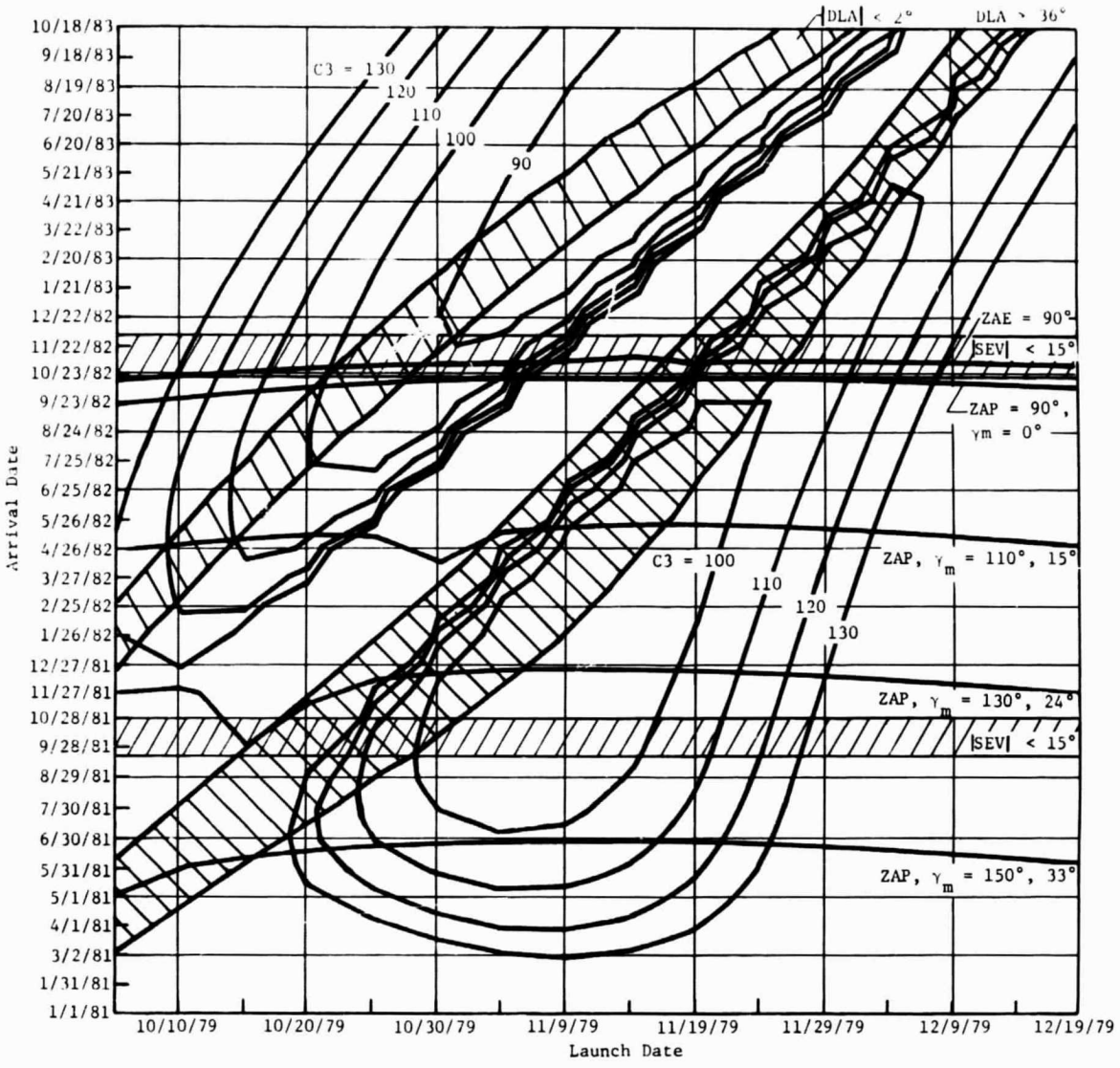


Fig. K-9 Jupiter Turbopause Probe Study
1979 Launch, Type I and II
(TF at X, Y = (0,0) is 454 Days)

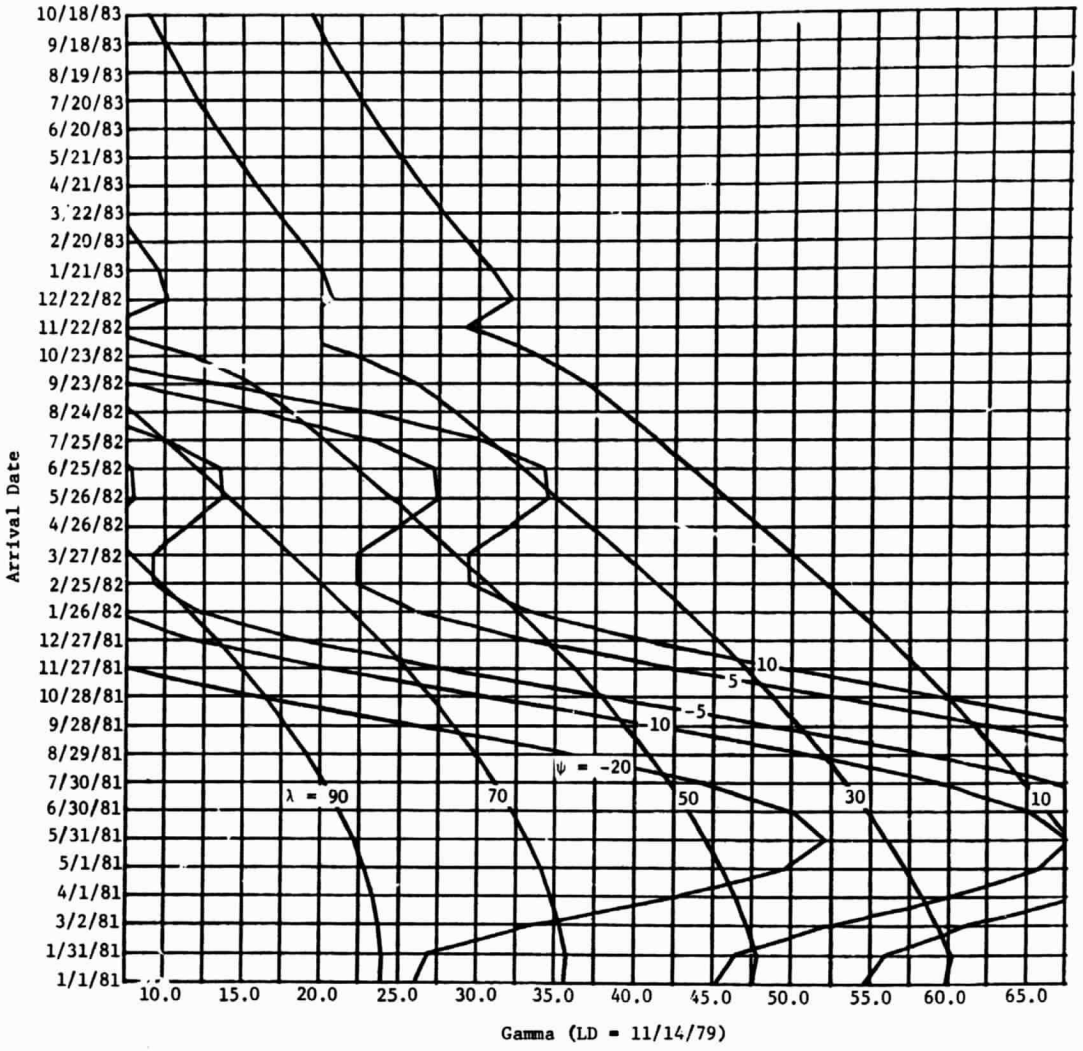


Fig. K-10 Jupiter Turbopause Probe Study
1979 Launch, Type I and II
(TF at X, Y = (0,0) is 454 Days)

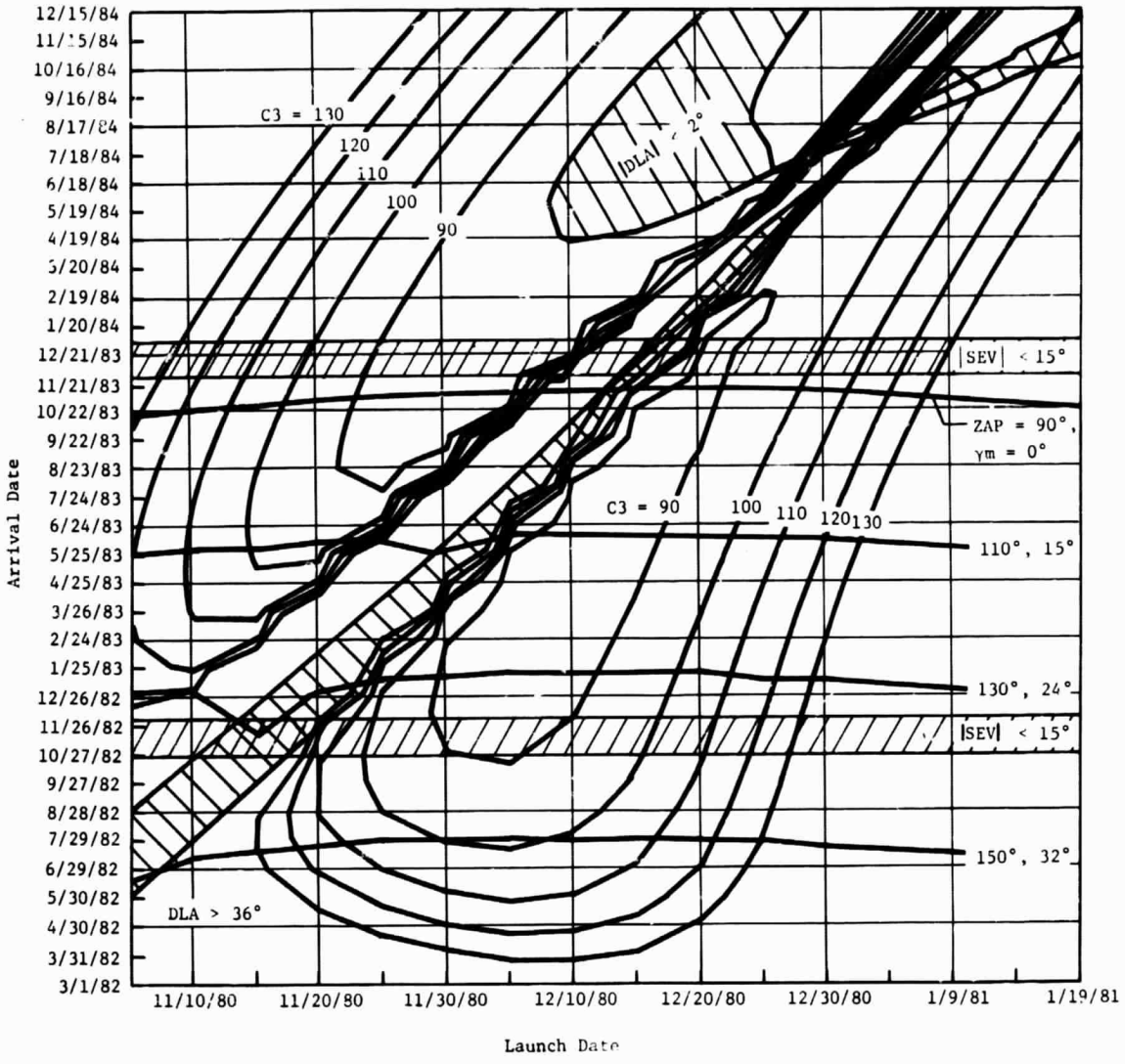


Fig. K-11 Jupiter Turbopause Probe Study
1980 Launch, Type I and II
(TF at X, Y = (0,0) is 481 Days)

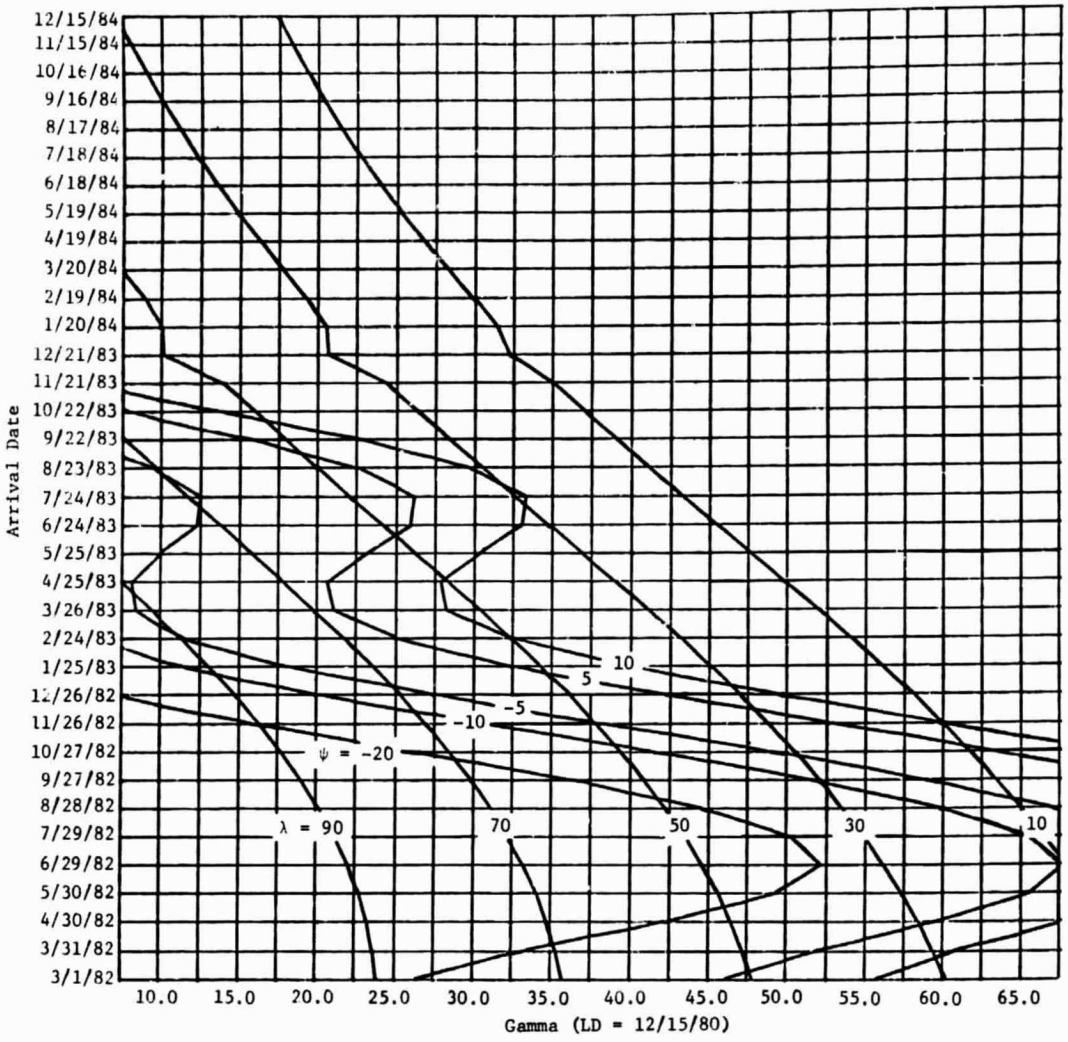


Fig. K-12 Jupiter Turbopause Probe Study
1980 Launch, Type I and II
(TF at X, Y = (0,0) Is 481 Days)

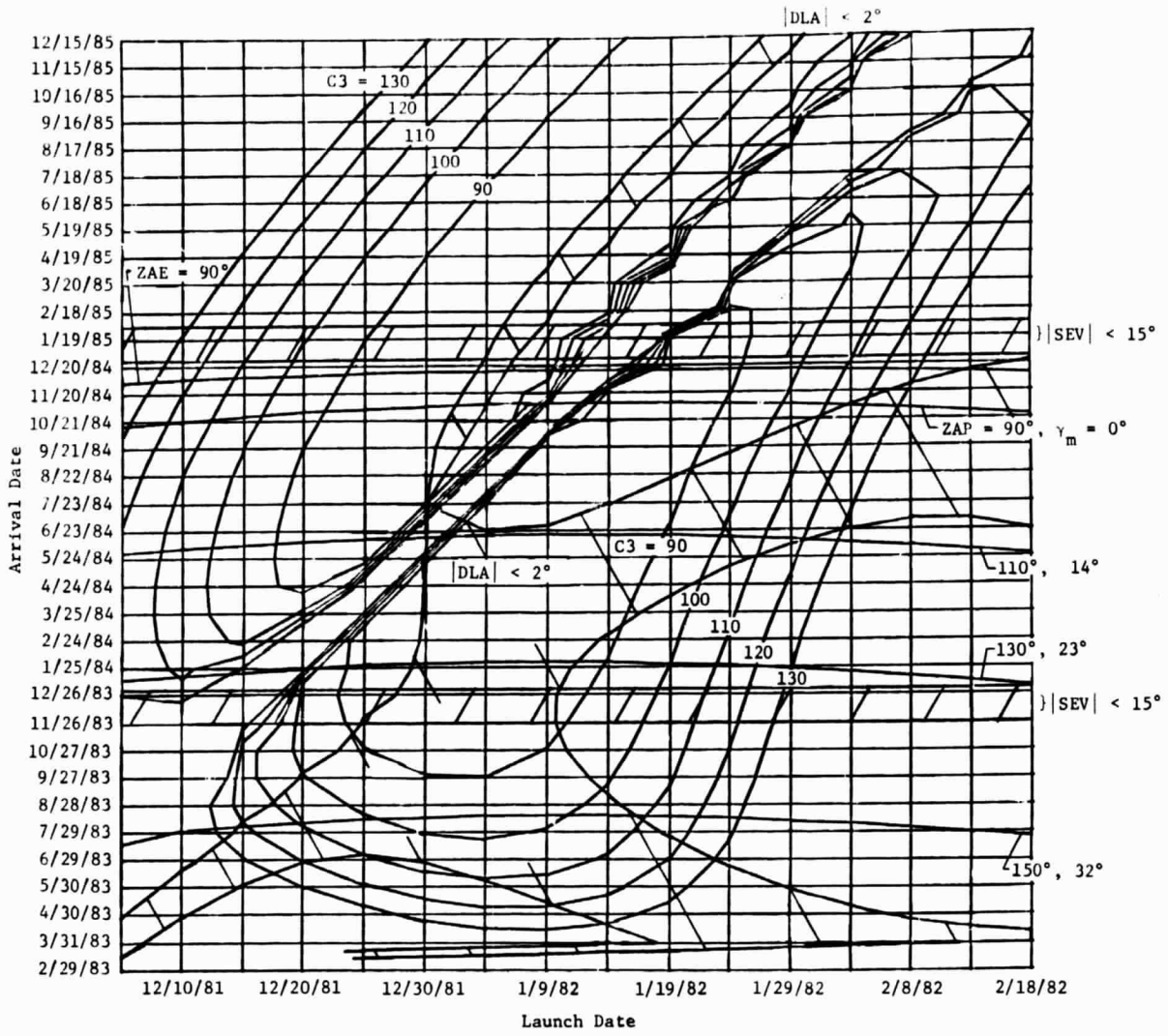


Fig. K-13 Jupiter Turbopause Probe Study
1981-82 Launch, Type I and II
(TF at X, Y = (0,0) Is 451 Days)

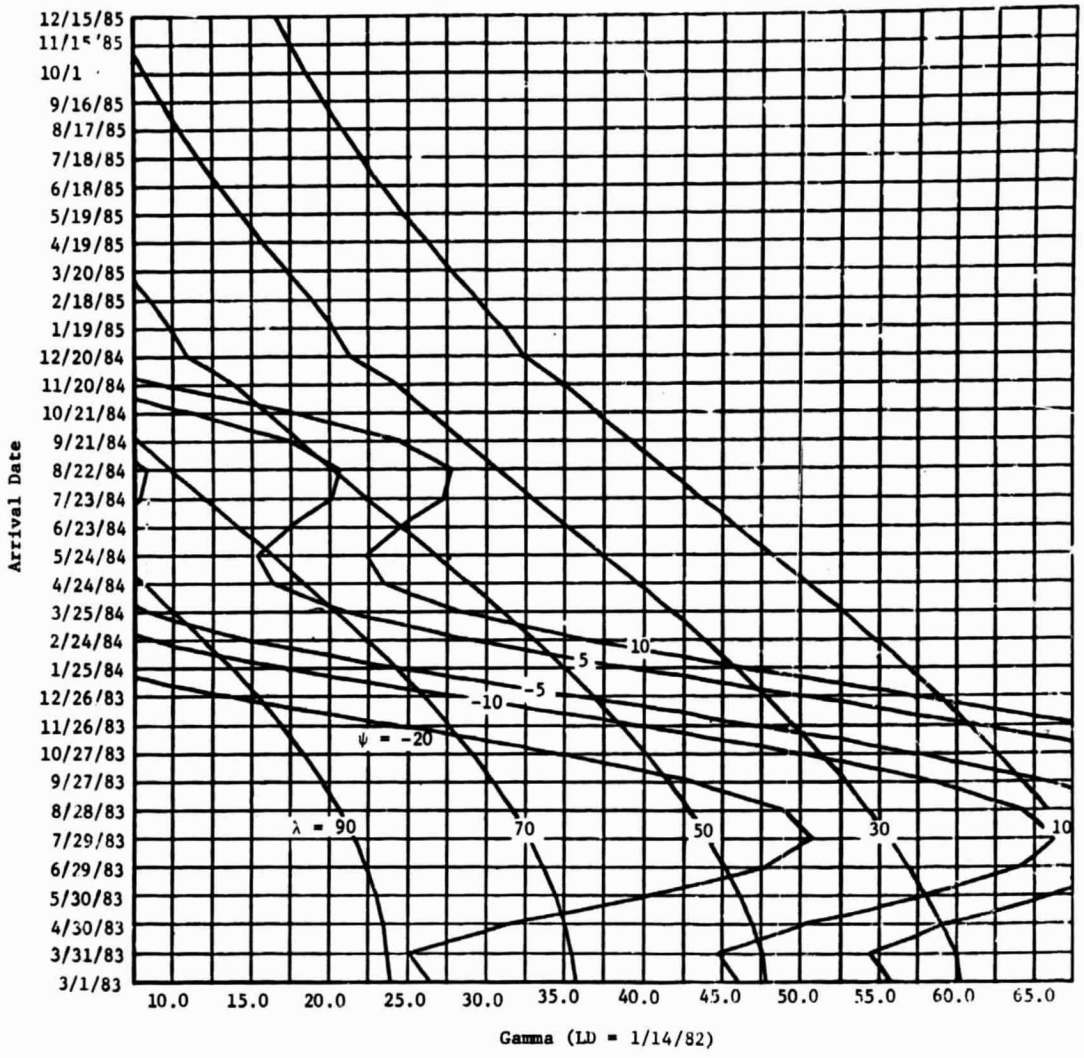


Fig. K-14 Jupiter Turbopause Probe Study
1981-82 Launch, Type I and II
(TF at X, Y = (0,0) Is 451 Days)

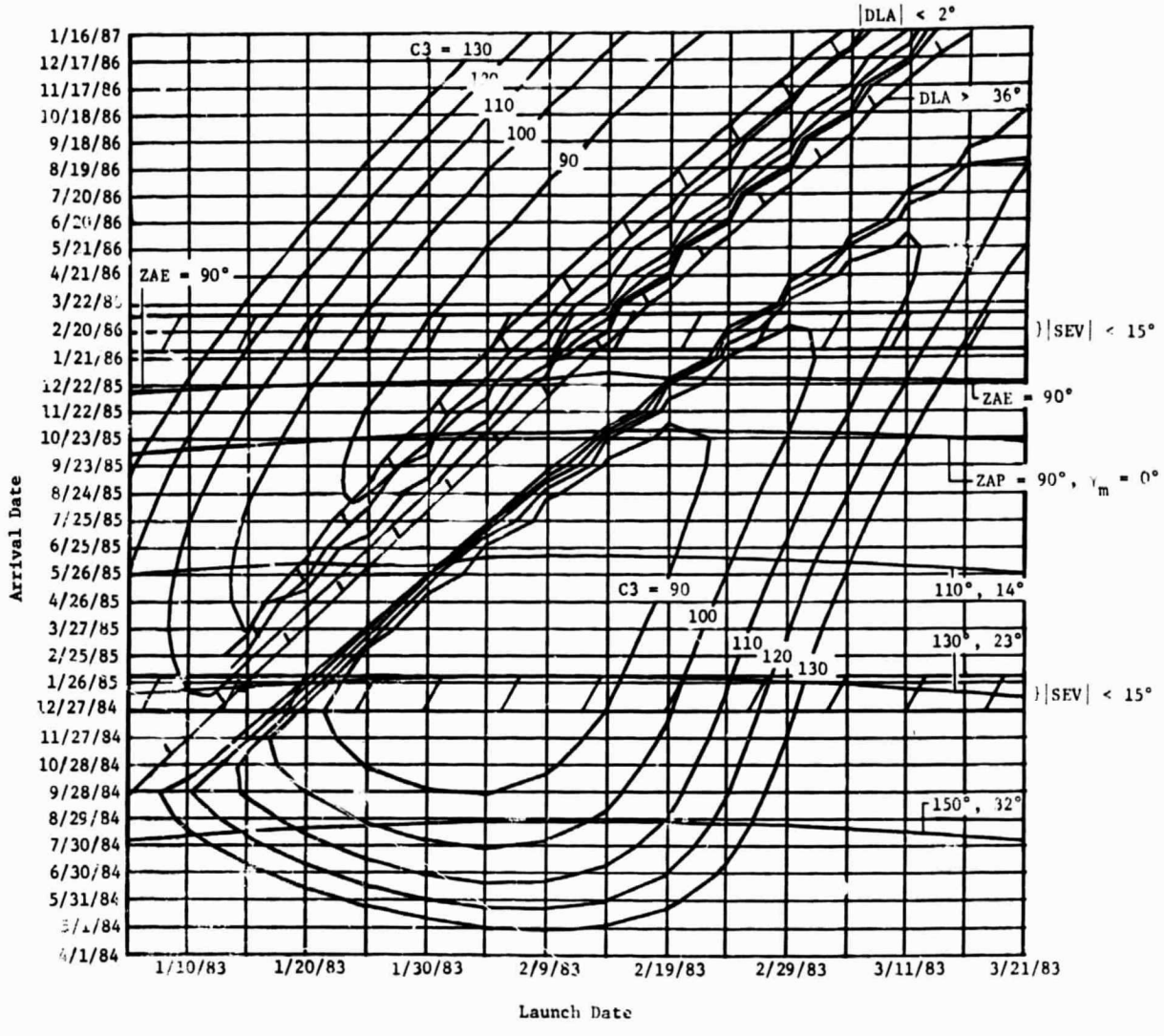


Fig. K-15 Jupiter Turbopause Probe Study
1983 Launch, Type I and II
(TF at X, Y = (0,0) Is 451 Days)

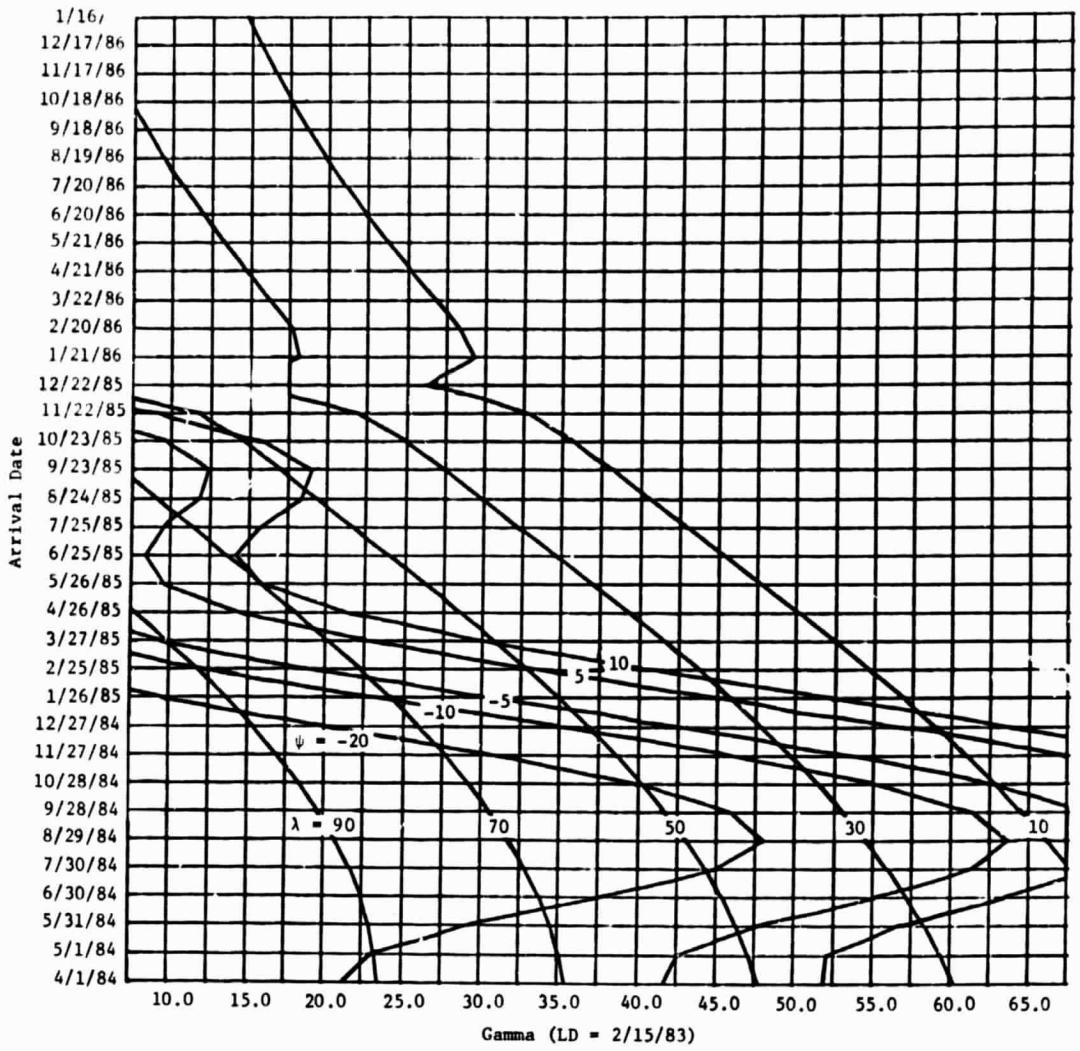


Fig. K-16 Jupiter Turbopause Probe Study
1983 Launch, Type I and II
(TF at X, Y = (0,0) Is 451 Days)